CRANFIELD UNIVERSITY

GEORGIA AGORI

SCHOOL OF ENERGY, ENVIRONMENT AND AGRIFOOD
Water and Wastewater Engineering

The Behaviour of Haloacetic Acids in Distribution Zones in Scotland

MSc by research

Academic Year: 2013 -2014

Thesis submitted for the Degree of Master of Science
Supervisor: Dr. Emma Goslan
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ABSTRACT

HAAs are the second most prevalent class of DBPs after THMs in chlorinated drinking water and are of concern due to their potential human health risk. Their concentrations in drinking water are regulated by the US Environmental Protection Agency (US EPA) and other regulatory agencies and are currently under consideration by the European Union to be regulated at 80μg/L. However their monitoring in the distribution system is complicated because several parameters influence their formation and speciation. In addition the kinetics of HAAs and their formation and stability remain largely unidentified. The HAAs are not as chemically or biologically stable as THMs in aquatic systems and their stability may impact their measurement.

The levels of HAAs within a distribution system may vary seasonally and spatially. Many studies have shown that their concentration in a distribution system can rise as well as fall. The levels of HAAs in the distribution system could be increased in the presence of residual chlorine or due to the decomposition from other DBPs and be decreased by biodegradation or hydrolysis and abiotic degradation. However biodegradation is likely the major loss process occurring in drinking water distribution systems.

This study provides an interesting picture of HAAs levels in distribution water in Scotland. A statistical analysis has been carried out using measurements of HAAs concentrations and other water quality parameters from 298 Scottish water distribution zones in to investigate the relative occurrence and speciation of HAAs, and determine their behaviour in water distribution systems, monitoring differences between zones. This study also allowed evaluation of the impact of seasons on HAAs concentrations and speciation in Scotland's distribution zones.

The results obtained show that the median concentrations of HAA_5 is 11.5μg/L. The average HAA_5 in distribution systems were about 50% lower than total trihalomethanes (THMs). In 0.7% of the zones under study, the average HAA_5 concentration exceeds 60μg/L. These zones are supplied by small WTWs (<3,300 people) and are using chlorination.

HAAs concentrations varied according to their water source and the disinfection strategy used. Low HAA_5 levels (the median was <5.3 μg/L) were observed in the groundwater systems and higher levels were observed in the surface water systems (the median was 12.4 μg/L). The chloraminated waters have lower HAA_5 and THMs levels compared to chlorinated waters, but the difference is not that pronounced. Generally chlorinated HAAs dominated in the waters of the distribution under study. The dominant species were trichloroacetic acid (TCAA) and dichloroacetic acid (DCAA). DCAA and TCAA were present at almost in equal levels in chlorinated waters but DCAA was the dominant group detected when using chloramination. Furthermore seasonal variations of the concentrations of different HAAs species were observed. The concentrations of HAA_5 were higher in summer and autumn and lower in winter and spring but the difference was not statistically significant. THMs has a similar seasonal pattern but with a more pronounced variation than HAAs. The median data show almost no seasonal variation for dichlorinated HAAs. However the seasonal variation of TCAA is more pronounced and higher concentrations were detected during summer and autumn.

When the data sets from all distribution zones were combined there was a strong correlation between total THMs and HAA_5, total THMs and TCAA and HAA_5 and total organic carbon (TOC).
The spatial variability of HAAs and THMs concentrations in two distribution zones using different disinfection strategies (chloramination and chlorination) was also studied. There has previously been no full scale study in the UK with the attempt to link the behaviour to distribution factors such as microbial water quality or distribution mains material.
In both systems THMs generally presented stable and increasing concentration profiles along the system, whereas HAAs increased and decreased, a phenomenon probably related to biodegradation. There is also evidence that abiotic reduction of HAAs is possible in the iron pipes for the chlorinated distribution system.
Using flow cytometry we observed generally higher levels of total and intact cells in the chloraminated distribution zone. Thus large numbers of dead cells can contribute to HAAs formation.

Keywords:
Disinfection By-products, Chlorination, Chloramination, Disinfection, Drinking Water, Drinking Water Distribution System,Water treatment works, Trihalomethanes, Natural Organic Matter, chlorine,

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LIST OF ABBREVIATIONS

AR Annular reactors
BAC biologically activated carbon
BCAA Bromochloroacetic acid
Cl_2 Chlorine
DBAA dibromoacetic acid
DBPs disinfection by-products
DBCAA Dibromochloroacetic acid
DCAA Dichloroacetic acid
DXAA Dihalogenated acetic acids
FCM Flow cytometry
GAC granular activated carbon
GC Gas chromatography
HAAs haloacetic acids
HAA_3 Sum of three HAAs (µg/l)
HAA_5 Sum of five HAAs (µg/l)
HAA_6 Sum of six HAAs (µg/l)
HAA_9 Sum of nine HAAs
HOBr hypobromous acid
HOCl hypochlorous acid
HPC heterotrophic plate count
ICP-MS Inductively coupled plasma mass spectrometry
LOD Level of detection
MCAA Monochloroacetic acid
MBAA Monobromoacetic acid
MCL Maximum contaminant level
MS Mass spectrometry
MtBE Methyl tert Butyl Ether
NOM natural organic matter
RGF Rapid Gravity Filtration
SUVA Specific ultraviolet absorbance
TBAA Tribromoacetic acid
THMs trihalomethanes
THM4 Sum of four THMs
TOC Total organic carbon
TXAA Trihalogenated acetic acids
UK United Kingdom
UKAS United Kingdom Accreditation Service
USEPA United States Environmental Protection Agency
UV254 Ultraviolet absorbance at 254 nm
WHO World Health Organisation
WTWs Water treatment works

Chapter 1: Introduction

1. Introduction

1.1 Background

Disinfection is one of the most important processes for producing safe drinking water and controlling waterborne diseases. Chlorination is the most common disinfection strategy applied by water treatment facilities throughout the world because of its economical availability, effectiveness against a wide range of bacteria, viruses and other pathogenic organisms and due to its property of maintaining an adequate residual in the distribution system to prevent re-growth of pathogens [1].
This disinfection strategy, however, leads to the formation of potentially harmful by products called, disinfection by-products (DBPs) which are formed by the reaction of chorine with natural organic matter (NOM) like humic substances and inorganic ions such as bromide/iodide present in water [3, 4]. DBPs are considered potentially carcinogenic and more recently, studies have shown a relationship between long-term exposure to DBPs and increased risk of cancer and adverse reproductive outcomes [2, 9, 10]. Trihalomethanes (THMs) and haloacetic acids (HAAs) are the major DBPs detected in chlorinated water [1, 2]. THMs have already received the most attention and are studied in detail because of their early discovery and ease of measurement coupled with their suspected carcinogenicity to humans and animals. In addition, HAAs are also of concern due to their potential human health risk and their concentrations in drinking water are regulated by the US Environmental Protection Agency (US EPA) and other regulatory agencies.
The main HAAs of concern in drinking water are the nine chlorinated and/or brominated species that include monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), dibromoacetic acid (DBAA), tribromoacetic acid (TBAA), bromochloroacetic acid (BCAA), bromodichloroacetic acid (BDCAA) and dibromochloroacetic acid (DBCAA) [14] with MCAA, TCAA, DCAA being the dominant compounds for most systems [15,16].
The US EPA has regulated the maximum contamination level (MCL) under the Stage 1 disinfectants/disinfection by-products (D/DBPs) rule for the total of 5 HAAs (MCAA,DCAA,TCAA, MBAA and DBAA) in drinking water to be 60 μg/L. Health Canada has fixed recommendations at 80 μg/L in 2008 and WHO has established guidelines for chlorinated HAAs (MCAA: 20 μg/L; DCAA: 50 μg/L; TCAA: 200 μg/L), but not for brominated HAAs [8].
On the other hand, there is no limit in the European Union (EU), including UK, for HAAs. Only THMs are currently covered by legislation in EU and the regulation limits for total THM concentration in drinking water are 100 μg/L. An MCL of 80μg/L for total HAAs however is suggested in a recent revision of the Drinking Water Directive [15, 17, 24]. Furthermore a recent report to the UK Drinking Water Inspectorate has recommended that HAAs should be included as a high priority (the highest category) in the list of regulatory chemical parameters to be routinely monitored [9].

However the monitoring of HAA in the distribution system is complicated and several parameters influence their formation and speciation: amount and nature of NOM,

concentration of bromide ion, pH, Temperature, dose of disinfectant and its contact time with the water [24, 1, 3, 9, 11]. The kinetics of HAAs, their formation and stability remain largely unidentified. Current knowledge supports that their formation occurs faster than THMs, particular species have shown tendencies to decompose at elevated pH values, and some species are known to biodegrade in the absence of chlorine residual [32]. The stability of HAAs play a key role, it is an important question that may impact their measurement [33].
HAA occurrence in chlorinated water may vary significantly based on season and geographical location in the distribution system. These variations are due to changes in raw and treated water qualities as well as operational parameters related to chlorination [17, 34].

During warm months there exists a higher concentration of NOM, a higher than average temperature and so an increased rate of microbial growth. For these reasons chlorination doses can be higher during treatment, resulting in substantially higher levels of DBPs during this period. An increase in chlorine dose causes an increase in the level of HAA and THMs [1, 3].

Spatial changes of HAAs in the distribution system are also important because treated water prior to consumption can spend an extensive amount of time within the distribution system, thus it is essential to calculate the possible growth of DBPs over this time period [44]. Some studies have shown that the behaviour of THMs and HAAs in the distribution system is different. THMs were observed to increase in the distribution system and become stable in the distribution system extremities, whereas HAAs decrease as water residence time increases within the distribution system after an initial increase [3, 47]. In warm water the decrease of HAA according to the residence time is higher than observed in cold waters where microbial activity is minimal [3, 11].

Biodegradation is considered to be responsible for the decrease in HAAs along the drinking water distribution system [11, 15]. Several studies have shown the involvement of microorganisms in the degradation of HAAs in the absence of disinfectant residual (e.g high residence time locations) [11, 48].
However biodegradation is likely the major loss process occurring in drinking water distribution systems [30] although other degradation reactions have been reported: hydrolysis (decarboxylation) and abiotic degradation by iron pipes and the resulting corrosion products [14, 30, 50], sorption or reaction within the pipe surface. Thus pipe surface is a crucial factor affecting all of the processes above [50].

1.2 Project objectives

Little is know about the levels of HAAs in drinking water in Scotland and this study provides an interesting picture of these compounds levels in consumers' taps in Scotland. A four-season occurrence survey of HAAs is held in order to measure HAAs concentrations in distributed water (in 298 distribution zones in Scotland). The first part of the project aims to investigate the relative occurrence and speciation of HAAs, and determine their behaviour in water distribution systems, monitoring differences between zones and variations throughout seasons.
Furthermore there has previously been no full scale study in the UK to investigate the behaviour of HAAs in distribution and no attempt to link the behaviour to distribution

factors such as microbial water quality or distribution mains material (diameter, length, and material). Thus on the second part of the project a key focus will be on linking chemical and microbial water quality to HAA behaviour in distribution system specifically using flow cytometry (FCM). The second area of research focuses on a chlorinated distribution zone of concern (with higher exposure as HAA_5 >20ug/l) and a chloraminated one. Moreover the impact of the two most common disinfection strategies on HAA formation and fate is investigated.
Information gathered on the distribution systems such as residence time and pipe material is combined with the analytical data to gain an understanding of each system. As a result sampling of two distribution zones (one chlorinated and one chloraminated) will be useful to measure all these parameters in the same time period. A novel aspect of this project is the use of FCM to enumerate the viable bacteria.

1.3 Organisation of report

This report consists of 5 chapters including this introductory chapter and chapter 2 which contains the literature review. Chapter 3 contains the materials and methods used to meet the objectives of the project. In the first part of that chapter the sampling plan and information gathered on the distribution systems are presented. In the second part the different methods of water samples analysis and the HAAs analysis method in detail are described.
Chapter 4 present the results of the study. In the first part the results of the HAAs occurrence in Scotland are presented with their seasonal variation and comparisons between the different water systems. The second part is focused on the results of the two distribution zones of concern (HAA_5>20µg/l) in order to determine a link between HAAs behaviour and distribution factors such as chlorine residual, bacterial levels and mains material (diameter, length, material). Moreover the impact of the two most common disinfection strategies on HAAs formation and fate is investigated.
Chapter 5 presents a summary of the findings of the research and the conclusions as they apply to the overall project objectives.

Chapter 2. Literature review on HAAs

2. Literature review on HAAs

2.1 Disinfection By-products formation, Health effects and Regulations

Disinfection of drinking water is critical to protect the public from disease-causing microorganisms. At the beginning of the twentieth century, prior to the disinfection of drinking water, thousands of people died from serious infectious diseases (for example, typhoid, hepatitis and cholera) due to pathogenic organisms in the water supply system.
Chlorination is the most common disinfection strategy applied by water treatment facilities throughout the world because of its economical availability, effectiveness against a wide range of bacteria, viruses and other pathogenic organisms and due to its property of maintaining an adequate residual in the distribution system to prevent re-growth of pathogens [1].

However, since the late 1970s public health concern raised about the disinfection process, [2] when researchers began to show that this disinfection strategy leads to the formation of potentially harmful by products called, **disinfection by-products (DBPs)** which are formed by the reaction of chlorine with naturally occurring organic matter (NOM) like humic substances and inorganic ions such as bromide/iodide present in water [3, 4, 5].
Since then, more than 600 DBPs have been found in treated drinking [6], with **Trihalomethanes (THMs) and haloacetic acids (HAAs**) being the major DBPs detected in chlorinated water on a weight basis [1, 2].
However chlorine is not the only disinfectant involved in the formation of DBPs and specially HAAs. Alternative disinfectant practices like chloramines, chlorine dioxide, ozonation, UV-irradiation typically produce smaller amount of these types of chlorinated DBPs [7] but they can form several other regulated and non regulated or ‘‘emerging’’ DBPs as well, some of them less studied up to now, but with higher potential toxicity; like chlorite, bromate, chloral hydrate, haloacetonitriles, nitrosamines, haloketones, haloamides, haloacetaldehydes [4, 8].

DBPs, as mentioned before, are considered potentially carcinogenic and more recently, toxicological studies have shown a relationship between long-term exposure to DBPs and increased risk of cancer and adverse reproductive and developmental outcomes [2, 9, 10]. Therefore the control of DBP formation has become one of the major issues for the drinking water sector. The objective of utilities is to provide treated and disinfected drinking water which protects consumers from pathogens while reducing DBP formation in order to adhere to present and forthcoming governmental standards.

Trihalomethanes (THMs) have already received the most attention and a significant amount of research has been conducted on THMs, but haloacetic acids are a relatively new disinfection by-product in terms of research, also of concern due to their potential human health risk.

Furthermore in a number of systems, their concentrations are found to be equal or greater than the THM's concentrations. Hence HAAs are a significant DBP in chlorinated drinking water and their monitoring in the distribution system is essential [11, 12]. In surface waters HAA are present at ng/L to μg/L concentrations, in drinking water distribution systems in μg/L and in treated wastewater in μg/L to mg/L [13].

The main HAAs of concern in drinking water are the nine chlorinated and/or brominated species that include monochloroacetic acid (MCAA), dichloroacetic acid (DCAA), trichloroacetic acid (TCAA), monobromoacetic acid (MBAA), dibromoacetic acid (DBAA), tribromoacetic acid (TBAA), bromochloroacetic acid (BCAA), bromodichloroacetic acid (BDCAA) and dibromochloroacetic acid (DBCAA) [14] with MCAA, TCAA, DCAA being the dominant compounds for most systems [15,16]. Especially for the UK, studies of Malliarou and Xhang show that the dominant compounds of various water distribution systems of UK are TCAA and DCAA [9, 17]. The sum of MCAA, MBAA, DCAA, TCAA and DBAA concentrations is known as HAA_5.

DCAA has been classified as a group B_2 chemical (i.e., a probable human carcinogen) by the Integrated Risk Information System of the United States Environmental Protection Agency (U.S. EPA) and TCAA as a group C compound (possible human carcinogen) [18]. Furthermore, both of these compounds have been proven to be animal carcinogens [19].
The formation, control, and health effects of HAAs, THMs and other disinfection byproducts (DBPs) in drinking water are issues of international concern and a significant amount of research on them has been conducted in the last decades. Thus the last ten years, many developed countries, as well as the World Health Organization, have established maximum acceptable concentrations of DBPs in drinking water.

The only regulated HAAs at this time are HAA_5, because occurrence data on tribromoacetic acid, dibromochloroacetic acid and bromodichloroacetic acid, collectively referred to as HAA_3, were limited and none of the current published methods for analysing HAAs could quantify HAA_3 accurately and in a reproducible manner [20,21].
The US EPA, in December of 1998, has regulated the maximum contamination level (MCL) under the Stage 1 disinfectants/disinfection by-products (D/DBPs) rule for the total of 5 HAAs (MCAA,DCAA,TCAA, MBAA and DBAA) in drinking water to be 60 μg/L, 80 μg/L of THMs. MCLs were also established for bromate at 10 μg/L, a by product of ozonation and 1000 μg/L for chlorite a by-product of chlorine dioxide [20,22].
The Stage 2 DBPR was promulgated on December 15, 2005 to further reduce acute (short term) exposure to high DBPs levels that occur periodically e.g during summer when temperatures are highest, and consequently decrease potential cancer, reproductive, and developmental risks. [23]
Under Stage 2 of the D/DBP rule, water utilities will need to comply with the same MCL as in the Stage 1 rule, but the monitoring must occur at locations with high disinfection byproduct concentrations. This approach is referred to as the locational running annual average (LRAA) and determines compliance by calculating the running annual average of samples from all monitoring locations across the system.

(as an average at these locations instead of as a system-wide average as in previous rules) [23,24].

Health Canada has fixed recommendations at 80 μg/L in 2008 for HAA_5 and WHO has set up guidelines for chlorinated HAAs (MCAA: 20 μg/L; DCAA: 50 μg/L; TCAA: 200 μg/L), but not for brominated HAAs [8]. However it is important to consider HAA_9 when analysing DBPs, because researchers have shown that HAA_9 levels can be 20-50% higher than HAA_5 levels in high bromide concentration of the chlorinated water and because these brominated species might have greater effects on human health, as being potentially more carcinogenic than chlorinated counterparts. [2, 8, 20, 25]

In Taiwan the limits for THMs and bromate are 80 and 10 μg/L respectively and there is no yet regulation for HAA, however a limit of 60μg/L has been proposed. In Japan total THMs are regulated at 100μg/L. In addition bromate, MCAA, DCAA and TCAA are regulated at 10, 20, 40, and 200μg/L respectively. In China the limits for THMs, DCCA and TCAA are 100, 50 and 100μg/L respectively [2]. In Australia and New Zealand the regulated limits of MCAA, DCAA and TCAA in drinking water are 150, 100 and 100 μg/L respectively [24, 26]

On the other hand, currently there is no limit in the European Union (EU), including UK, for HAAs. Only THMs are currently covered by legislation in EU and the regulation limits for total THM concentration in drinking water are 100 μg/L. An MCL of 80μg/L for total HAAs (HAA_9) however is suggested in a recent revision of the Drinking Water Directive [15, 17, 24]. Furthermore a recent report to the UK Drinking Water Inspectorate has recommended that HAAs should be included as a high priority (the highest category) in the list of regulatory chemical parameters to be routinely monitored [9].

2.2 Chemistry and formation of HAA

DBP precursors can be organic, such as NOM, or inorganic, such as bromide and/or iodide present in the natural water source. HAAs are formed in water treatment plants and distribution systems principally through the reaction of this NOM and Bromide ions if present with free chlorine species, hypochlorous acid (HOCl) and hypochlorite (OCl^-). The aqueous speciation of them is pH dependent [27].

As an electrophilic species the aqueous chlorine often reacts with electron-rich sites within organic structures such as activated aromatics and b-dicarbonyl aliphatics [28]

The most common pathway for HAAs formation has been observed by scientists to be chlorine species reacting with humic organic materials, specifically with structures which are know to be aromatic. Notwithstanding, the reaction pathway data regarding the formation of HAA is still considered insufficient and additional research work has been apportioned to the identification of potential functional groups present in water, responsible for the formation of HAAs [29]. Moreover HAAs can also form in the distribution systems due to the hydrolysis of other chlorinated DBPs [30, 31].

HAAs can be subdivided into three species: mono, di and tri halogenated species. Each of the mono halogenated species is likely formed through similar chemical pathways and likewise the di halogenated and the tri halogenated species [11, 24].

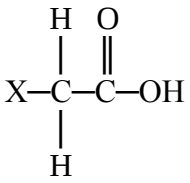
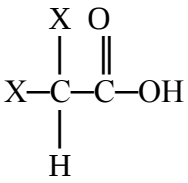
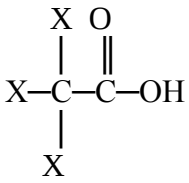
Monohaloacetic acid	Dihaloacetic acid	Trihaloacetic acid
		
X=Cl or Br	X=Cl or Br	X=Cl or Br

Table 2.1 Structures of the three groups of HAAs

Several surveys have been carried out in USA and Canada and less in the EU to estimate the distribution of HAAs and THMs and the parameters affecting their formation and ultimate concentration in drinking water. Their speciation is dependent on several factors concerning the water quality and operational conditions. (e.g pH, chlorine dose, contact time) [24].

The formation and fate of THMs has been adequately researched to show THMs do not typically fluctuate whilst in water distribution systems. By contrast HAAs are less researched and understood. The kinetics of HAAs and their formation and stability remain largely unidentified. Current knowledge supports that their formation occurs faster than THMs, particular species have shown tendencies to decompose at elevated pH values and other species are known to biodegrade in the absence of a chlorine residual [32]. HAAs stability remains an important question that may impact their measurement [33].

HAA levels may vary significantly based on season and geographical location in the distribution system. These variations are due to changes in raw and treated water qualities as well as operational parameters related to chlorination [17, 34]

2.2.1 Factors affecting formation of HAAs

Different research has suggested that other than the chemical characteristics of natural organic material (NOM) in the water (e.g specific ultraviolet absorbance of the water, [SUVA], hydrophilic versus hydrophobic dissolved organic carbon [DOC]), there are various operational and water quality factors that influence the formation of HAAs in

chlorinated drinking waters; like the type of disinfection scenario (chlorination only, chlorination/chloramination, or ozonation/chlorination) and chemicals, water treatment process, nature of water source, bromide content, pH of chlorination and distribution, temperature, concentration of total and free chlorine, residence time, distribution system characteristics and levels of total organic carbon (TOC)[1, 3, 9, 11].

NOM precursors

The concentration and characteristics of NOM, which are the principal DBPs precursors in the chlorinated water, varies significantly from one source to another and play a major role on the relative distribution of HAAs and THMs. The pathway and quantity of HAA formation depends on the concentration of the organics and on the distribution of ‘‘fast -reacting’’ and the ‘‘slow –reacting” with disinfectans [35]. A large number of research works have been concerned with the identification of functional groups associated with the formation of DBPs, which could potentially be carboxylic acids, aromatic, amide, amino acids, phenol, alcohol, ketone etc [29].

The NOM present in water contains both hydrophobic and hydrophilic organic material, products of the degradation and leaching of the organic detritus within the watershed. The nature and distribution of the hydrophobic and hydrophilic organic materials in different waters may differ, depending on the parent organic material and the biogeochemical process involved in carbon cycling within the specific watershed. [32].

Generally, the hydrophobic fraction, which contains more aromatic carbon and phenolic hydroxyl groups, has been reported to be more reactive in producing HAAs than the corresponding hydrophilic fraction. SUVA has been widely used as a surrogate parameter for the hydrophobicity and aromaticity of NOM in water and was shown to be moderately correlated with the HAA and THM total formation potential. SUVA (expressed in L/m.mg C) is defined as the UV absorbance (1/m) of a given sample determined at 254 nm and divided by the DOC concentration (mg/L) of the sample, and can give information on the nature of NOM present in the sample [17].
Thus high SUVA values tend to produce more HAA than waters having low SUVA, which are dominated by hydrophilic organic carbon [11].
To better understand the reactivity of NOM towards the formation of DBPs, NOM is generally characterised by measuring its total organic carbon (TOC) or dissolved organic carbon (DOC) concentration, its SUVA to display the amount of aromatic material, and its potential to form DBPs. Hence, the amount (described as DOC or TOC) and the nature (described as SUVA) of NOM will give some insights into the DBPs formed.

Nature of water source

The formation of DBPs depends primarily on source water quality characteristics. The total HAA levels in water supply systems vary considerably according to their water source. [9]. Treatment facilities which procure their water from surface water like rivers, reservoirs, and lakes are apt to yield drinking water with higher levels of HAAs and disinfection by-products than water treatment facilities who derive their water

from groundwater sources. [9]. Groundwater is naturally filtered, and because of this artesian wells and springs, and pumped wells tend to produce water with relatively low concentrations of NOM.

However compared to surface water, ground water usually has higher levels of inorganics such as bromide [20, 22, 36]. The speciation of HAAs depends on the nature of water source. For example high levels of bromide ion in the source water may lead to a high proportion of brominated DBPs in the investigated water [3, 20, 22]

Inorganic precursors: Bromide

During chlorination of drinking water bromide, if present in the water, is oxidised by the free chlorine to aqueous bromine in the form of hypobromous acid (HOBr) or hypobromite ion (OBr^-) depending on the pH. These oxidants, as with chlorine species, react with NOM to form the potential harmful halogenated DBPs [25].
These reactions between bromine and NOM have been reported to be faster than those with chlorine. Chlorine typically occurs at higher concentrations than bromine and competition between the two halogens for substitution sites is intense [25].

In the absence of bromine only chlorinated species will be formed. However if bromide is present in the water, it shifts the HAA and THM to bromide containing ones and it leads to a higher percentage of brominated and mixed bromo-chloro species of HAA and THM and a total increase in concentration if all THM and HAA species are measured [37]. The effect of bromide is greater in THM formation than in HAA and dependent on several factors including chlorination conditions (chlorine dose, reaction time, pH and temperature) TOC concentration and precursor's characteristics [25].

Due to the relatively high atomic weight of bromine, the formation of brominated DBPs causes a significant increase in the total DBPs concentration and make it more difficult to meet the DBP regulations if significant amount of both bromide and precursors are present in the source water [25].

Water treatment process

As mentioned above HAA formation is highly dependent on source water characteristics such as SUVA, proportion and nature of hydrophobic NOM and bromide concentration. Treatment processes that can change these parameters, such as coagulation, will alter DBP formation during the subsequent disinfection process.
Coagulation followed by clarification and/or filtration is the common process used to remove turbidity and NOM from surface waters [38]. Nonetheless, it remains more efficient to use coagulation for the removal of the majority of hydrophobic and high molecular weight fraction of NOM [11, 39]. High SUVA hydrophobic NOM has proved to be often more susceptible to coagulation [32].
Thus this treatment step removes considerable amounts of DBP precursors and shifts the distribution of HAA and THM species. Enhanced coagulation is the best available technology for reducing DBP precursors. A large percentage of water treatment

facilities have begun to boost the coagulant dosage along with adding acids to coagulate water at lower pH levels, in contrast with established conventional coagulation for turbidity removal [2]. Chlorinated DBPs precursors can be minimised by oxidation (the use of ozone, for example), by membrane filtration processes and by activated carbon absorption [38].
Combination processes have also emerged to deal with DBPs precursors like micro or ultrafiltration membranes combined with coagulation and ozone/biofiltration.
Among the newest innovations has been the use of magnetic ion exchange resins, nanofiltration and precipitative (enhanced) softening [2].

The conditions under which the disinfection process is performed also have significant impact on HAA formation and species distribution:

Disinfection scenario

As mentioned before chlorination has been a strategy commonly applied by water treatment facilities throughout the world and the UK. However water systems in UK are converting to chloramines (combined Chlorine) as a primary and/or secondary disinfectant in their treatment plants, because monochloramine can reduce the occurrence of THMs in distribution system. Generally in the UK, the water is exposed to free chlorine for 30 minutes before ammonia is added at a weight ratio of 3:1 to 4:1 of Cl_2:N [4].
Chloramines include monochloramine (NH_2Cl), dichloramine ($NHCl_2$) and trichloramine (NCl_3), with monochloramine being the predominant chloramine species present under the conditions typically found in water treatment works and distribution systems.
In practice, chloramination involves adding ammonia and chlorine, usually with chlorine first. The period of free chlorine contact time and the time before ammonia addition are very significant for the formation of DBPs [4]. Different studies show that after chloramination lower concentrations of HAAs are detected compared to chlorination and that chloramination suppress the formation of trihalogenated acetic acids [35, 40, 41].
Thus during monochloramination the predominant HAA were dihalogenated species (DXAAs) and less incorporation of bromine into HAAs was observed compared to that during chlorination [4, 35]. However the formation of DXAAs can still reach significant levels depending on the dose, chlorine to ammonia ratio, pH and other conditions [7]. Chloramines stability within the distribution system provides an additional edge allowing for adequate taste and odour control as well as favoring biofilm control [38].

Moreover the conditions under which the disinfectant is used, such as the disinfectant dose, point of addiction, contact time, pH and residual disinfectant concentration play a very important role in the extent of DBPs. Thus the formation of DBPs depends on the location in the treatment process where disinfectants are added. Generally, all other factors being equal, fewer DBPs will be formed when the disinfectants are added later in the treatment process [32].

Dose of chlorine applied

THM and HAA formation tends to increase with increasing chlorine dose [37, 41, 43]. Thus the higher the applied dose the higher the levels of HAAs. Moreover the kinetics of TCAA formation are favoured by higher chlorine concentrations and the amount of TCAA acid is greater than that of di and monochlorinated species with this increase [1, 44].

Contact time

THM and HAA formation was observed to increase with increasing reaction time [37, 43]. Experimental research carried out using bench scale conditions have shown that concentrations of both species increase with increasing contact time in the presence of chlorine [34]. Moreover re-chlorination of distributed water, followed by several hours of residence time in a storage tank has a significant increase of THMs and HAAs [3].

However in the distribution system, where the water may travel days to reach the customers tap, as later will be discussed, the conditions are different and the concentrations of THM increase along the distribution system, whereas the HAA may have different comportment.

pH

pH is one of the principal factors controlling the distribution of HAA and THMs. A higher pH is associated with lower levels of HAAs and higher levels of THMs [1, 11]. However, among the HAA species, the formation of trihalogenated acetic acid species tends to decrease with increasing pH whereas dihalogenated and monohalogenated acetic acid species are relatively independent of pH [11]. At pH values exceeding 8, free chlorine water will have lower HAA to THM ratio than water which is distributed at lower pH levels [11]. This is due to the fact that at high pH, base catalysed hydrolysis reactions are favoured, yielding more THM [1]. Reckhow and Singer stated that THM and TCAA evolve from a common precursor structure (R-CO-CX3) and the relative formation of these DBP species is determined by the nature of the R group and the pH [43].

Temperature

Temperature certainly has a significant impact on the formation of HAAs and THMs. The rate of formation of DBPs is shown to be increased with an increase in temperature. Studies indicate a correlation between THMs and water temperature.
Furthermore during summer months there often exists a larger level of NOM compared to winter, a higher average water temperature and so an increased rate of microbial growth. For these reasons chlorination doses can be higher during treatment, resulting in substantially higher levels of DBPs during this period. An increase in chlorine dose causes an increase in the level of HAA and THMs [1, 3, 8]. On the other hand, temperature does not correlate as well with HAA concentration in distribution systems. The rate of formation of HAA increases with an increase of the

temperature. However increasing temperature accelerates the chemical and biological degradation rates of some HAA species [17, 42].
A lot of studies have shown the chemical and especially the microbiological degradation of HAA because of the presence of distribution system biofilm, a phenomenon associated with warm waters [34].
It is also shown that high temperature favours the formation of DCAA rather than TCAA, maybe because this compound is not thermally stable contrary to DCAA. When water temperature increases TCAA can be transformed gradually into other species, in particular chloroform and CO_2 [1, 34, 45]

Therefore most studies showed that HAA concentrations were higher in the warm season and lower in the cold season. For example studies in Canada have shown that during summer and spring higher concentrations of HAA were found compared to the winter with the highest noticed in spring. There are two possible reasons for that: some degradation of HAA occurs at higher temperatures and that greater occurrence of precursors exists this season that favour the formation of HAA [3, 6]
Similarly in US maximum levels were found during summer and a study in the UK indicates that greater amounts of HAA are found again during summer and autumn and lower during winter and spring [11, 24].

2.3. Seasonal and spatial variations of DBPs in distribution system

The levels of chlorinated DBPs within a distribution system may vary seasonally and spatially. HAA formation and HAA degradation are the major processes that could change their concentration in a distribution system [31].
Many full-scale and bench-scale studies are available regarding the seasonal and spatial variations of THMs and HAAs in the distribution systems of several regions around the world such as the U.S.A, Canada, Australia, Taiwan, China, France, England and Turkey [6, 12, 20, 22, 24, 36, 43, 46].

2.3.1 Seasonal changes of HAAs in the distribution system

The seasonal variations are influenced by variations in water temperature, the amount and type of NOM, raw and treated water quality parameters during the year, and operational parameters (e.g. chlorine dose, pH adjustments) during treatment, which are the response to these water changes [34]. Moreover season affects microorganism survival and activity, an important factor in HAAs degradation.

In most of the cases the lowest amounts of HAAs are detected in winter and the highest in summer, spring and autumn. Interestingly in a study in Turkey they found that the lowest concentrations of HAA_9 were during summer [12, 20, 22].

Variations in water quality depend on climatic conditions that are specific to each region of the world (temperature, precipitation etc.). Hence it would be difficult and

maybe a mistake to compare the results of studies on temporal variations of water from different regions [6].
Another limitation of comparing data from previous studies is the use of different HAA metrics. Some studies used HAA_5, others HAA_6 and some others HAA_9 [20,22]. Furthermore some studies are bench scale and others full scale. Rodriguez et al. suggest that the behaviour of DBP species in full-scale studies is not the same as under laboratory conditions [34].

2.3.2 Spatial changes of HAAs in the distribution system

Spatial changes of HAAs in the distribution system are also important because treated water prior to consumption can spend an extensive amount of time within the distribution system, thus it is essential to calculate the possible growth of DBPs over this time period [44]. The increase of water residence time along the distribution system combined with the decreasing concentration of free and total chlorine influence the spatial variability of the concentrations of the various DBPs along the distribution system [6].

The spatial variation of THMs levels in distribution systems is well recognised. THMs were observed to increase in the distribution system and become stable in the distribution system extremities. This is due to the combination of the continuous chemical reaction between NOM and chlorine forming THMs, along with the hydrolysis reactions of intermediate DBPs which break down in order to form THMs [2]. However studies have shown that the behaviour of THMs and HAAs in the distribution system is different. Thus HAAs, decrease as water residence time increases within the distribution system after an initial increase [3, 47]. As a rule, a greater reduction of DCAA is observed in the water distribution system than for TCAA [6, 16]. In warm water the decrease of HAA according to the residence time is higher than observed in cold waters where microbial activity is minimal [3, 11].

Thus the location with the highest THM concentration normally are the points in the distribution network of longest retention time but the location of highest HAA concentrations is less clear due to the fact that THM do not degrade once formed, whereas HAA compounds tends to degrade with time to other species after formation. A peak concentration of HAA would be somewhere in the middle of the system with concentrations declining at distant points within the system [42].
However opposite results have been reported by Singer et al. with stable and increasing HAA concentrations in the distribution system. [13, 41].

Seasonal and spatial variations and correlation found between THMs and HAAs are not necessarily transferable to other distribution systems, because as mentioned before their concentrations depend on the climate, types of water, treatments, and disinfectants used [6].

Spatio-seasonal variations of DBPs are a concern to water plant managers, water epidemiologists and water regulators as it is difficult to predict their fate and thus the human exposure to DBPs in drinking water on both a seasonal and spatial basis [34].

2.4. Degradation of HAAs in the distribution system

The HAAs are not as chemically or biologically stable as THMs in aquatic systems. Their concentration in the distribution system could be increased in the presence of residual chlorine or due to the decomposition from other DBPs and be decreased by biodegradation or hydrolysis and abiotic degradation [31]
Studies show that biodegradation is considered to be responsible for the decrease in HAAs along the drinking water distribution system [11, 15]. Several studies have shown the involvement of microorganisms in the degradation of HAAs in the absence of disinfectant residual (e.g high residence time locations) [11, 48]. The presence of low concentrations of HAAs at the end of the distribution system, where the disinfectant residual is low and bacterial heterotrophic plate counts (HPC) are high is another proof of the biological degradation of HAAs [31, 49] . In contrast to the biodegradation of HAAs species, most THMs are not biodegraded [48].

However biodegradation is likely the major loss process occurring in drinking water distribution systems [30] although other degradation reactions have been reported: hydrolysis (decarboxylation) and abiotic degradation by iron pipes and the resulting corrosion products (iron minerals) [14, 30, 50], sorption or reaction within the pipe surface. Thus pipe surface is a crucial factor affecting all of the processes above [50].

The abiotic degradation reactions however are not likely to play an important role. This is due to the reason that at environmental pH and environmental temperature values these reactions are slow or they require specific combination of conditions such as a potent reductant (Fe0) and trihalogenated HAAs with one or more bromine atoms [30]. Hydrolysis may also lead to DBP losses in a distribution system but other DBPs may be produced as end products. For example in basic solutions haloacetamides further hydrolyse to form haloacetic acids or trihalogenated acetic acids (TXAA) can decompose to form their corresponding THMs [51, 52]. However Hozalski et al. showed that hydrolysis of HAAs doesn't seem to be an important loss of HAA as it was not observed for experiments lasting up to 2 weeks [52]

2.4.1 Biodegradation

Even if disinfection is applied to drinking water and very low nutrient concentrations are achieved bacterial regrowth is possible. Many microorganisms adapt to live in these harsh conditions and become resistant to the disinfectant residual present. Microorganisms have the preference to get attached to solid surfaces creating aggregates of microorganisms with their extracellular polymeric material, called biofilms [53]. Their density on the pipe walls can be up to 107-108 cells/cm^2 of pipe and may multiply in favourable conditions (low residual chlorine, warm water) or released from pipe surfaces and transport to other parts of the distribution system [30]. HAAs can be biodegraded under aerobic conditions through a hydrolysis-oxidation pathway and reductive dechlorination [52, 54]. There are many studies reporting the

biodegradation of some HAAs species in soils and wastewater or by organisms obtained from those environments [15].
However in the water distribution systems HAAs are present in lower concentrations. Moreover water distribution systems are unique and harsh environments for microorganisms due to their chlorine content and their oligotrophic environment. Thus in these environments different microorganisms with different genetic and physiological characteristics are found than in soil and wastewater [15]. As typically in water distribution systems, the effluent contains 8-10 mg/L of dissolved oxygen (except some anoxic areas) and suspended bacteria and the biofilm on the pipe wall typically are exposed to aerobic conditions, the hydrolysis-oxidation pathway is more likely to occur [14, 52]

Reports showing the biodegradation of HAAs in water treatment systems such as biologically active filters, but also in water distribution systems first emerged in the late 1990s [15, 30, 31, 55]. Most of these reports show that HAAs are easily biodegradable and their concentrations may be lower at locations in the distribution system with high bioactivity [31] such as locations with longer residence time and low chlorine residual.
However the factors that affect their biodegradation in the distribution systems are not clearly understood. Lack of degradation was observed in many drinking water distribution systems and this was probably due to high concentration of residual chlorine or lack of HAA degrading organisms, or environmental factors like pH, temperature and micronutrient limitation [55].
According to Grigorescu and Hozalski, an amount of biomass above 105 bacteria/cm^2 is necessary to obtain a significant degradation of HAAs. Moreover the diameter of the pipes has an impact on HAA degradation. Pluchon et al. showed that DCAA degradation drops when diameter increases [16]. Seasonal changes affect HAA degradation not only because they influence the kinetics of the reactions but also because they have a major impact on the amount of biomass present in the distribution system and the composition of NOM.

Baribeau and colleagues evaluated the microbial degradation of HAAs in annular reactors (AR) and showed that when the residual was absent, the dihalogenatid acetic acids were biodegraded under warm water conditions. The trihalogenated acetic acid species, however were not biodegraded under similar condition, nor were the THMs [2]. In the presence of a free chlorine residual, both classes of HAA species and the THMs continued to form and in cold water their biodegradation is not apparent [56].
Dihaloacetic acids were removed by granular activated carbon (GAC) filters to a greater degree than trihaloacetic acids, but both groups were removed, [2, 30] in contrast to the AR study and other distribution system and controlled laboratory studies, which showed that the trihalogenated acetic acids are not biodegradable [48].
However Tung et al., using Heterotrophic Plates Counts, showed that both di and trihalogenated acetic acids were biodegradable in distribution system locations with high bioactivity and McRae et al. showed the biodegrability of TCAA by bacterial enrichment cultures in a slower rate [30, 31]. Moreover Zhang et al. found that trihalogenated HAA species are more stable than mono and dihalogenated species [15].
Literature on the biodegrability of mono species of HAA in drinking water conditions is limited as their concentrations are usually bellow detectable limits [48]. However several studies with bacterial enrichment cultures have shown their biodegrability and

sometimes they were the most degradable followed by the dihalogenated species [13, 15, 48, 49, 56]. Hozalski et al. showed that monohalogenated species were the most biodegradable with DCAA and TBAA being the next most biodegradable and TCAA and DBAA being the least biodegradable. Furthermore research showed that MCAA and MBAA biodegradation mechanisms involve the same enzymes and regulatory systems in many different types of bacteria [13].

However the source of the bacterial culture plays a role in the relative order of biodegrability of the HAAs [48]. Several different bacteria can aerobically degrade HAAs either cometabolically or as a sole carbon and energy source but little is know about these organisms (i.e. identity, substrate range, degradation kinetics) [13, 15, 49, 52]. As mentioned previously the hydrolysis-oxidation reaction is responsible for the biodegradation of HAA which is catalysed by an α-halocarboxylic acid dehalogenase enzyme [30].
For example for the MCAA the halogen atom (Cl) is replaced by a hydroxyl group in the presence of the enzyme. The resulting product glycolic acid is processed through the metabolic pathway and gets readily mineralised [30].
$ClCH_2COOH + H_2O \rightarrow C_2H_4O_3 + Cl^- + H^+$
Several genes encode those enzymes and are grouped into two distinct phylogenetic classes of genes called dehI and dehII. These classes are characterized by high intragroup genetic diversity [30]. Zhang et al. suggested that only drinking water isolates having a dehI gene could degrade trihalogenated acetic acids and those containing both a dehI and dehII gene could biodegrade all chlorinated and/or brominated HAA species tested [55].
There is a lot of literature concerning the identity and physiology of HAA degrading-organisms but no precise information is currently available regarding the abundance and the diversity of HAA-degrading bacteria in drinking water systems [30].
HAA degrading bacterial strains such as Burkholderia sp, Xanthobacter sp., Sphingomonas sp., Chrysobacterium sp. were isolated from soil and activated sludge. The isolation of HAA-degrading bacteria from water systems is very difficult and time-consuming. As it is difficult to culture microorganisms from chlorinated and especially chloraminated tap water samples [49] most studies of HAA degraders cultured them from biofilm samples or from prechlorinated GAC filters and distribution system pipe walls [49]. Moreover, it is possible that the obtained HAA-degrading isolates are not the environmentally relevant HAA degraders in drinking water systems, due to the cultivation bias [30].
Zhang et al. [15, 55] isolated HAA-degrading bacteria from different locations along drinking water systems, including biologically active carbon (BAC), and found that Afipia spp. appeared to be important HAA degraders in these systems and important HAA degraders in UK drinking waters. However, the isolates obtained by Zhang et al. from drinking water systems (from pipe wall and granular activated carbon biofilms), suggested that there is very little overlap in the species obtained from water systems and those from other environments, suggesting that the specific conditions in water systems (oligotrophic environment, chlorine residual) select for unique HAA degrading bacteria. Another HAA degrader in tap water mentioned in the literature is Methylobacterium sp. [52].
To sum up the role of microorganisms in the fate of HAA in drinking water distribution system remain poorly understood and more work is needed to be done regarding the identification and characterisation of the HAA degrading organisms in these systems and their functional genes involved in HAA biodegradation [13, 15].

Generally the microbial ecology of water distribution system including HAA degrading organisms is not clearly understood [30, 49]. HAA-degrading biomass in drinking water systems are not known because of the difficulty in obtaining biofilm samples, especially from distribution system pipes, and because of the lack of a rapid and reliable method for quantifying HAA degraders in the samples [30].

2.4.2 Effect of the pipe wall

HAAs as with other DBPs may be degraded abiotically via hydrolysis and abiotic reduction (reductive dehalogenation) to a variety of degradation products in the water distribution system. Of course these reactions depends on the environmental conditions (pH, temperature, Fe minerals present, bacteria present etc.). Furthermore HAA may be sorbed onto or react within the pipe surface [50, 52, 57]. Therefore the interior surface of pipes is a crucial factor affecting all of the processes above, but only limited amount of reports are examining the effect of pipe materials on the formation and fate of DBPs and HAAs.

The pipes distrubiting drinking water vary greatly in materials used and include: ductile iron, steel, cast iron, cement-lined ductile iron, galvanized iron, poly (vinyl chloride), fiberglass and copper [50, 54]. The most commonly used material in drinking water distribution systems are ductile/unlined cast iron and steel [54].

Typically the interior surface of an unlined cast iron pipe is exposed to an oxidising environment because the flowing water contains both dissolved oxygen and free or combined chlorine, which are potent oxidizing agents [52, 54]. When zero valent iron comes in contact with water, Fe^{2+} ions are formed according to the following reaction: $Fe\ (0) \rightarrow Fe^{2+} + 2e-$ [57].

The oxidants oxygen, free chlorine (HOCl, OCl^-) or monochloramine interact with iron of the pipes which is a powerful reductant (acceptor of the released electrons) and causes the corrosion of the iron pipes and the build up of a variety of partially or fully oxidised iron mineral deposits [52, 54, 57]. Fe (II) ions are being added continuously in drinking water distribution systems from these iron corrosion products [57]

$$O_2 + 4H^+ + 2e^- \rightarrow 2H_2O \quad (1)$$
$$HOCl + H^+ + 2e^- \rightarrow H_2O + Cl^- \quad (2)$$
$$NH_2Cl + 2H^+ + 2e^- \rightarrow NH_4^+ + Cl^- \quad (3)$$

Source of equations: [57]

The extent of corrosion and the quantity and composition of the corrosion products is site specific and may vary within individual systems due to variability in hydraulic conditions, pipe age, water quality [52, 54]. Biofilms also present on pipe walls are succeptable to accelerate the corrosion in the lower layers of the biofilms [53].
Several studies have reported that zero valent iron reduces HAAs [52, 57]. It has been observed that when Fe (0) is present HAA undergo sequential hydrogenolysis (replacement of a halogen by hydrogen) with bromine preferentially removed rather than chlorine and the terminal reaction produces acetate. [14, 52].

The age of the pipe has demonstrated to make a difference as the percentage of Fe (0) on the surface of the pipe may be less than 10%, which suggests the HAA degradation may not be relevent. Be that as it may most of the iron water mains were laid down down decades ago and are corroded. Thus reduction by Fe (II)/(III) of corrosion solid products and absorbtion to iron minerals are potential loss pathway for HAAs [14, 54].
Therfore reduction at the pipe wall could occur through zero valent iron or by ferrous iron contained in or sorbed to iron oxide corrosion products [52]. Goethite, magnetite and green rust were reported to be the dominant corrosion products on iron pipe surfaces in Columbus, Ohio, Boston in the US [52].

Fe(0) reduction has illustrated the susceptibility of HAA in the following order: tri HAA, di HAA and lastly mono HAA, which proves to be the opposite of HAA biodegradability. Dehalogenation intermediates or end products are typically observed to be di and mono HAA [58]. Furthermore it has also been reported that Fe(0) and corrosion byproducts such as magnetite and goethite can reduce other DBPs and produce HAAs and THMs.

On the other hand it is well established that the ferrous corrosion products and Fe (II) react with free chlorine present in pipe water distribution systems, thus there is less chlorine available to react with HAAs precursors [57]. During summer when higher temperatures occur, chlorine consumption by pipes and NOM is promoted [16]. Moreover iron tubercles have been shown to contain organic material that includes DBP precursors [44].
All the above show again that the formation of HAA, their speciation and their fate in a distribution system is a complex phenomenon and depends on several factors including characteristics of water, treatment procedures, water distribution pipe materials.

2.5. Relationship between HAA and THMs

Several studies looked at the correlation between HAAs and THMs, because THMs totals could be used as a surrogate for HAA levels.
HAA formation is such a complex function of so many variables and the interaction of different parameters in a distribution system makes its prediction harder, it is useful to find surrogate parameters to estimate or monitor HAA production in water utilities under a wide range of condition. A good correlation between THMs and HAAs can be useful because, in general, laboratory analyses for HAAs cost considerably more and are also more time consuming than the THM analyses.
However this may not be appropriate as correlation between HAAs and THMs was poor in some studies [3, 9] but some others studies have reported moderate to high correlation between HAAs and THMs across different water systems in various countries [20, 22, 40, 41].

As mentioned before these two groups of chlorinated DBPs have different behaviour according to season and location, so THMs may not be a good surrogate of HAA levels within a specific distribution system. Their correlation may be better in cold

water in locations with low residence time, comparing to warm water [34]. Their correlation is heavily dependent on water temperature, residence time and water source [20, 22]. However the THMs in distribution can give an insight into the degradation behaviour of HAAs. At room temperature the trihalogenated acetic acids (TXAA) can decompose to form their corresponding THMs via decarboxylation. So it is important to determine the speciation of the haloacetic acids, with the speciation changing depending on whether the degradation is microbial or abiotic, not only due to their toxicity but also due to their contribution to the formation of THMs [51].

2.6. HAA occurrence and speciation in UK

In the UK, chlorination is the most common disinfection strategy, after the water has been treated by coagulation and filtration. It should be noted that chlorine and chloramines are applied to water after the entire treatment process. In US different practices are used where pre-chlorination is widely used [37]. However an increasing number of water utilities of UK are switching to chloramines as a primary and/or secondary disinfectant in order to reduce the levels of DBPs and especially THMs.

Work focusing on identifying the specific organics responsible for the DBP formation in UK drinking water will be very useful to adapt the water treatment to remove HAA precursors from the raw water [37].

HAAs are not routinely measured in the UK and little is known about their formation and their fate in the water distribution system [37]. Malliarou study reports HAA levels up to 244 μg/L with DCAA levels fairly high, above 100 μg/L [9]. However this study was preliminary and the sample size was small. A more extensive investigation of the occurrence of HAA_9 in UK treated drinking water, based on a sampling survey of three water utilities has observed lower concentrations of HAA depending on the water source and treatment [37]. The highest HAA concentration corresponded to upland surface water system and didn't exceed 40 μg/L. DCAA and TCAA were the principal HAA species that is general agreement with with Malliarou's survey and Goslan et al. [4].
In the UK the research of Bougeard et al., Zhang et al. [24, 37] indicate there may be a seasonal effect with higher HAA concentrations during summer and autumn and lower during winter and spring. However these seasonal differences were less important than those reported in previous studies. For example in Rodrigez et al. study the differences were fourfold [24].
Another survey by Goslan et al. in Scotland showed again a higher concentration of HAAs during summer with values reported up to 134 μg/L [4].

Zhang et al. investigated the spatial variation of HAA in the distribution system of three utilities in UK. The results show a higher concentration of HAA in all distribution systems than in the water leaving the water treatment work, with increased HAA concentrations with flow time through the distribution network. However an exception was found during autumn, where a decrease of DCAA and TCAA in one distribution system was noticed [24].

Moreover studies trying to identify and understand the degraders of HAA found that *Afipia* spp. appeared to be important HAA degraders in UK water systems [15, 55].

2.7. Conclusion

To sum up HAAs are a significant DBP in chlorinated drinking water and their monitoring in the distribution system is essential. However there monitoring in the distribution system is complicated and several parameters influence their formation and speciation.

Several surveys have been carried out worldwide to estimate the distribution of HAAs and the parameters affecting their formation and ultimate concentration in drinking water. These factors are related to the water quality and operational conditions like the amount and chemical characteristics of natural organic material (NOM) in the raw water, the type of disinfection scenario (chlorination only, chlorination/chloramination, or ozonation/chlorination) and chemicals, water treatment process, nature of water source, bromide content, pH of chlorination and distribution, temperature, concentration of total and free chlorine, residence time, distribution system characteristics and levels of total organic carbon (TOC).
In addition their kinetics of formation and stability are not well characterised. The HAAs are not as chemically or biologically stable as THMs in aquatic systems and their stability may impact their measurement.
The levels of HAAs within a distribution system may vary seasonally and spatially. Given the complex nature of the distribution systems and of the multiple factors that affect the formation and fate of HAAs and their interactions, is hard to predict what is happening in the real word. Many studies have shown that their concentration in a distribution system can rise as well as fall.
The levels of HAAs in the distribution system could be increased in the presence of residual chlorine or due to the decomposition from other DBPs and be decreased by biodegradation or hydrolysis and abiotic degradation. However biodegradation is likely the major loss process occurring in drinking water distribution systems.

Chapter 3. Materials and Methods

3. Materials and Methods

3.1. Four-season occurrence survey of HAA in Scotland

3.1.1 Sampling strategy

A four season sampling programme was undertaken between September 2013 and August 2014. HAA data (n=1690 samples) were collected from 298 distribution zones in Scotland. Out of 298 distribution zones, 246 were sampled 6 times in this study period and the rest (52 zones) 4 times. However there are some deflections from the initial sampling plan during the year (See initial sampling program in Appendices, Table A.1) Sample locations in the distribution system were random houses.
The samples were collected by Scottish Water operators and were analysed at Scottish Water laboratories.

Results of THM, TOC, pH, total and free residual chlorine were supplied from Scottish Water for most of the samples taken for HAA.
There is some bromide data, but unfortunately bromide was not analysed on the samples taken for HAA, but on different dates. However, the data should still correlate with the formation of brominated haloacetic acids and THMs.
There is no temperature data.

3.1.2 Water systems Characteristics

Each utility system consisted of a water treatment works supplying a distribution network, and the details concerning the disinfection method, the water source, the population served and water treatment stages of each system are reported in Tables 7.2 and 7.3 of the Appendices. All this information is based on 2013 data from Scottish Water.

Most of the zones used surface water and only 13. 1 % of the 298 zones used ground water during the study period. The principal type of disinfectant used by most utilities was chlorination and only 14. 4% of zones are supplied by chloraminated water.

3.2 Focus in two zones

3.2.1 Sampling strategy

Two distribution zones were selected to determine the behaviour of HAA in distribution. Drinking water samples were collected from the two distribution systems during the summer season in July 2014. These two zones were chosen depending on

the concentration of HAA (HAA_5 >20ug/l), their accessibility and the disinfection method used in the treatment works. Patheshill Zone was chosen as the chloraminated zone and Rosebery as the chlorinated zone.
The samples are analysed for HAAs, THMs, free and total chlorine, TOC, pH and bactreria counts by flow cytometery by Scottish Water laboratories.

However as it is difficult to calculate the water age, the distances from the WTWs are given for 5 or 6 different sampling locations. That involved some network tracing to find out the locations which are the furthest in distance from the WTW. By doing this we are assuming that the further away the postcode is, the greater the water's age will be. Furthermore as the pipe material may affect the fate of HAA in the distribution system, information about the distribution mains are gathered.

3.2.2 Water systems Characteristics

Rosebery:

Source Name:	Gladhouse reservoir	Megget reservoir
Catchment Activities:	Sheep, cattle, agricultural activities, forestry, fishing from rowing boats, migrating birds at Gladhouse Reservoir, Windfarm, Game rearing	
Source Type:	Upland Reservoirs	
Population served:	126,000 (Edinburgh, East Lothian, Penicuik, Borders)	

Table 3.1 Rosebery WTW characteristics

Raw water is subjected to the following treatment and disinfection procedure at the Rosebery Water Treatment Work (WTW). The first step of treatment is the conditioning and the coagulation/flocculation with Alum of the raw water. Then it is clarified in dissolved air flotation units. The water then passes through rapid gravity sand filters and after Orthophosphoric acid is added for plumbosolvency control.
Chlorine is added, for disinfection, before the contact tank, and finally pH correction is by lime.

The pipe material of Rosebery distribution system was a mixture of ductile, spun and cast iron, Asbestos Cement and mixed density polyethylene (High Performance Polyethylene, Medium Density Polyethylene, Polyethylene) with Polyvinyl Chloride and Unplasticised Poly Vinyl Chloride. (see Appendices, Table 7.11 for details about the material and diameter of the pipes)

Location	Samp.point	Iron material %	Distance from WTW (m)
ROSEBERY SOUTH EH32 9QX	1	92.06	33,543
ROSEBERY SOUTH ML12 6QZ	2	61.32	40,911
ROSEBERY SOUTH EH41 4JP	3	47.45	41,206
ROSEBERY SOUTH EH46 7BE	4	63.08	42,093
ROSEBERY SOUTH ML12 6JD	5	51.08	54,912

Table 3.2 Rosebery's distribution system sampling locations

Pateshill :

Source Name:	West Water Reservoir	Baddinsgill Reservoir
Catchment Activities:	Rough grazing, shooting, hill walking.	
SourceType:	Direct	
Population served:	58,803	

Table 3.3 Pateshill WTW characteristics

The first treatment step is flocculation.The raw water is dosed with PAC 18 and polyelectrolyte and clarified in precipitators. Then the clarified water passes through rapid gravity sand filters.Orthophosphoric acid is added for plumbosolvency control. As there was historically high THMs levels chloramination now is used for disinfection.Chlorine is added before the contact tank, and then ammonium sulfate is added. The normal dose ratio (Chlorine:Ammonia) is 4:1.Finally pH is adjusted with Lime.

The pipe material of Pateshil distribution system was a mixture of ductile iron, spun and cast iron and mixed density polyethylene (High Performance Polyethylene, Medium Density Polyethylene) with Unplasticised Poly Vinyl Chloride.
(see Appendices, Table 7.11 for details about the material and diameter of the pipes)

Location	samp.point	iron material %	distance from WTW (m)
PATESHILL EH47 7AA	1	100.00	6,421
PATESHILL EH47 8HA	2	65.57	10,726
PATESHILL EH48 1EN	3	84.15	16,541

PATESHILL EH52 6LN	4	91.35	19,231
PATESHILL EH49 6NF	5	93.44	25,410
PATESHILL EH52 6QN	6	94.92	32,869

Table 3.4 Pateshill's distribution system sampling locations

3.3 Sample collection

Before sampling water was run out for 5 minutes for clearing any standing water in the supply line. Water pH, total and free residual chlorine were measured in situ. Bottles for measuring TOC, THMs, flow cytometery and HAAs were collected and transported to the laboratory following the appropriate sampling and storage practices. For HAA analysis water samples were collected in 150 mL amber glass bottles with PTFE-lined screw caps. A dechlorination solution (sodium thiosulfate) was added to the bottles to avoid further DBP formation during the time between sample collection and analysis (10%W/V).
Samples must be stored in a calibrated refrigerator at 5±3°C prior to extraction. Samples must be extracted within 5 days from the sampling date. There is 7 days stability for monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, bromochloroacetic acid and dibromoacetic acid. Monobromoacetic acid only has 5 days sample stability. Extract stability, once extracted, is 4 days from the extraction date for monochloroacetic acid. Monobromoacetic acid, dichloroacetic acid, trichloroacetic acid, bromochloroacetic acid and dibromoacetic acid have 7 days extract stability.

3.4 Current Analytical Methods

3.4.1 HAA analysis

This method has UKAS accreditation for all components except Bromodichloroacetic acid, chlorodibromoacetic acid, and tribromoacetic because these components did not perform consistently over the validation, therefore these compounds are analysed for screening purposes only.

3.4.1.1 Principle

A known volume of sample is measured out and internal standard is added. The sample is then acidified using sulphuric acid and has sodium sulphate added, then extracted using MTBE. The Haloacetic acids are partioned into the organic layer and converted into their methyl esters to enhance the volatility of the analytes, by the addition of acidic methanol followed by heating for 2 hours. The organic layer

containing the methylated haloacetic acids is separated from the acidic methanol and neutralised by adding sodium bicarbonate solution.
The organic layer is concentrated by evaporation under gentle nitrogen flow then analysed by gas chromatography with mass spectrometric (MS) detection. The compounds of interest are detected using the MS in Selected Ion Recording (SIR) mode.
Quality assurance procedures included analysis of field blanks and the use of internal standard in each sample and standard.

3.4.1.2. The lower reporting limits of the method are:

Compound	lower reporting limits (µg/l)
Monochloroacetic Acid	<1.0
Monobromoacetic Acid	<0.8
Dichloroacetic Acid	<1.3
Trichloroacetic Acid	<1.1
Bromochloroacetic acid	<0.9
Dibromoacetic Acid	<1.1
HAA 5 Total	<5.3

Table 3.5 Lower reporting limits (µg/l) of each HAA compound

3.4.1.3. Equipment and Apparatus

-Calibrated Balances (suitable for weighing 20.0 ±0.5g).

-Calibrated 50µl, 100µl, 250µl, 500µl and 1ml syringe.

-Calibrated Turbovap Sample Concentration System.

-Perkin Elmer GC-MS System and software.

-DB-5MS capillary column (length 30m, internal diameter 250µm, film thickness 0.25µm) or equivalent

-Bottle Top Dispenser (5ml calibrated dispenser set to dispense 2ml)

-Fume-cupboard.

-Calibrated Muffle Furnace (set at 400°C +/- 20°C)

-Dessicator, containing self-indicating silica gel (#9.10).

-General laboratory glassware: beakers, measuring cylinders, pipettes, Pasteur pipettes, vials etc. as required.

-Glass pipettes.

-Cold Store (Capable of maintaining 5°C ± 3°C**)**

-Refrigerators (Capable of maintaining 5°C ± 3°C**)**

-Calibrated Autopipettes

-7.5ml Scoop

3.4.1.4. Reagents

-Ultrapure Water (or deionised water of same quality)

-MTBE (HPLC grade or equivalent) Expiry date and storage as detailed by manufacturer.

-Methanol (HPLC grade or equivalent) Expiry date and storage as detailed by manufacturer

-Concentrated Sulphuric Acid (>95% Analytical grade**)** Expiry date and storage as detailed by manufacturer.

-Anhydrous Sodium Sulphate (Analytical grade or equivalent). Dry at 400±20°C for a minimum of 4 hours in a calibrated muffle furnace .Allow to cool in a dessicator prior to use .This solid must be stored in a sealed glass bottle at ambient temperature, this is stable for 6 months.

-Saturated Sodium Bicarbonate Solution Add sufficient analytical grade or equivalent sodium bicarbonate to be in excess, to 500ml of ultra pure water in a glass standard bottle and shake well. This solution must be stored in a sealed 500ml glass bottle at ambient temperature, and is stable for 6 months.

-Sodium Thiosulphate Solution. Weigh out 25.0±0.1g of sodium thiosulphate and add to approximately 150mls of ultra pure water in a 250ml beaker and mix to dissolve. Transfer to a 250ml volumetric flask and make up to the mark with ultra pure water. Transfer to a 250ml amber glass stopper bottle. Store at ambient temperature. The solution is stable for 1 year.

-Acidic Methanol .Very carefully add 10ml of concentrated sulphuric acid using a 10ml glass pipette to methanol in a 100ml volumetric flask and make up to the mark

using methanol. Allow to cool to room temperature (a cold water bath may be used). After cooling, top up again to the mark with Methanol if required. This solution must be stored in a sealed 100ml glass bottle at ambient temperature. This solution is stable for 1 month.

-Matrix Water. The matrix water must be of a similar matrix to the type of water being analysed in the batch. Both potable and raw water samples may be extracted together with a potable matrix which is obtained from the tap on the day of use or bottled water may be used.

-Self-Indicating Silica Gel (Laboratory reagent grade or equivalent). Particle size approximately 4-8 mesh. Before use, dry in an oven at a minimum of 100±5°C until it has turned completely blue. When the gel turns pink it requires to be dried again, as before.

3.4.1.5. Sample Preparation

Sample Extraction

-Transfer 50ml of the sample into a clean 60ml glass vial with PTFE-lined screw cap, using a 50ml measuring cylinder.

-Add 50µl of internal standard (23/IS/04) to the sample using an appropriate syringe.

- Using a bottle-top dispenser, add 2ml of concentrated sulphuric acid (this will be enough to adjust the pH to 0.5 or less).

-Add approximately 15g of Sodium Sulphate and place the samples onto a rotary shaker for 10 minutes, by which time the majority of the sodium sulphate should have dissolved. Note: The sodium sulphate should be added immediately after the acid so the heat generated will help to dissolve the salt. The sodium sulphate may be measured using a heaped 7.5ml scoop.

- Add 5ml of MTBE, using a bottle top dispenser, and place on the rotary shaker for a minimum of 15 minutes.

-Allow the phases to separate for a minimum of 5 minutes. Using a Pasteur pipette transfer as much of the organic top layer as possible to a test tube with screw top, being careful to avoid transferring any of the aqueous layer as this will adversely affect the sample derivitisation. It is important to check that there are no cracks or chips in the tube as this may allow water to leak into the test tube during heating.

Sample Methylation

- Using a 1ml autopipette, add 1ml of Acidic Methanol to the test tube prior to adding the organic layer. Occasionally, if water is present in the sample, a white solid may form at this stage. This should dissolve upon heating. The test tube lid should then be

screwed on, making sure that the PTFE septa is present and intact and that the lid is tight enough to avoid the loss of any analytes during the derivitisation process.

- Place the test tubes into the turbovap at temperature 50±3°C for a minimum of 2 hours. This should be timed using a calibrated timer. Do not turn on the nitrogen as this step is for heating only not concentrating.

- After 2 hours remove the test tubes from the turbovap and allow to cool to room temperature before removing the screw-tops. It is important to wait until the samples have cooled sufficiently before removing the caps in order to avoid any loss of analytes due to evaporation.

- Very slowly add 4ml of the sodium bicarbonate solution. CAUTION: This will result in vigourous effervescence due to the carbon dioxide produced from the neutralisation reaction. When this has died down, invert each test tube a few times then allow the phases to separate. This stage should be performed as quickly as possibly.

- Using a pasteur pipette, transfer the organic layer to a test tube containing approximately 1cm of Sodium Sulphate. Sprinkle some more Sodium Sulphate over the extract, then leave to dry for a minimum of ten minutes - there is often water present in the MTBE at this stage and it can be difficult to tell if the extract is completely dry.

- Transfer the MTBE extracts from the test tubes into numbered Turbovap tubes. Place the tubes in the Turbovap set to 25±2ºC and use the sensor endpoint so that the samples blow down to 0.5mls.

- Using a Pasteur pipette, transfer each extract to a 2ml autosampler vial containing a glass insert. Quite often there can still be water present at this stage, which will cause the sample to appear slightly cloudy. A few granules of Sodium Sulphate should be added to the Turbovap tube as a precaution. However, care should be taken to not transfer any Sodium Sulphate into the autosampler vial as this can create problems with the syringe needle during analysis.

- Label every GC vial with a batch description and the sample description/number, and analyse using Perkin Elmer GCMS.

3.4.1.6. Calibration

Six calibration standards were used to prepare the calibration curve. Standards were extracted in exactly the same way as the samples.

To create a calibration curve the peak area/IS area was plotted against the standard concentration. Quantification of samples is calculated according to the following formula. This is done automatically by the integration software once the system has been calibrated.

Amount (Y) = area (Y)/RRF (Y) x Amount (I)/Area (I)

Where:

Amount (Y) is the amount in the sample/standard in µg/l.

Area (Y) is the peak area.

RRF (Y) is the relative response factor for peak (Y).

Amount (I) is the amount of Internal Standard in the sample.

Area (I) is the peak area for the Internal standard

That means, all peak areas were normalised with respect to the internal standard area for each sample.

3.4.1.6.1 Preparation of Calibration standards and AQCs

- ***Calibration Standards***

-23/C/10 2000ug/ml Haloacetic Acid mix: A certified stock mix which may be purchased from Sigma-Aldrich (49107-U or equivalent).

-Working Haloacetic Acid Calibration Standard (10mg/l in MTBE) 23/C/11: Add 500µl of the 2000ug/l Haloacetic Acid Mix 23/C/10 to a 100ml volumetric flask using an appropriate syringe, then make up to the mark with MTBE. The standard is stable for 6 months stored at 5±3°C.

-Extracted Standard: Measure 50ml of ultra pure water, using a measuring cylinder, into each of six 60ml screw-top vials. Add 50µl of Internal Standard (23/IS/04) using an appropriate syringe, then add the following volumes of Working Calibration Standard (23/C/11).

Extracted calibration standards are prepared with each batch of samples as outlined in the table below. These standards undergo the extraction procedure as described before.

Standard	Standard Concentration (µg/l)	Volume of 23/C/11 Calibration Soln (µl)	Volume of 23/IS/04 Surrogate (µl)
23/C/12	40	200	50
23/C/13	30	150	50
23/C/14	20	100	50
23/C/15	10	50	50
23/C/16	5	25	50

23/C/17	2	10	50
Blank	0	0	50

Table 3.6 Extracted calibration standards preparation

- ***Internal Standard***

All samples are spiked with the appropriate volume of 20 mg/l 2-bromobutanoic acid internal standard (50µl to 50ml of sample)

- 23/IS/01 Bromobutanoic Acid Internal Standard Stock: Commercially bought from Fisher (16451-00050) or equivalent. Must be >99% pure

-23/IS/02 1,2,3-Trichloropropane Stock Standard: Commercially bought from Sigma Aldrich (110124) or equivalent. Must be >99% pure.

-23/IS/03 Internal Standard intermediate: Weigh 0.100g±0.005g of 2-bromobutanoic acid (23/IS/01) into a 10ml volumetric flask containing approximately 6ml MTBE. Add 72ul of 1,2,3-trichloropropane using a 100ul syringe. Make up to the mark in MTBE. This standard is stable for 6 months stored at 5±3°C.

-23/IS/04 Internal Standard spiking solution: Add 25µl of internal standard intermediate (23/IS/03) using a 50µl syringe into a 25ml flask containing approximately 20ml MTBE. Make up to the mark with MTBE. This standard is stable for 6 months stored at 5±3°C.

- ***AQC Standards***

-Certified **Stock Haloacetic Acid Mix 2000ug/ml 23/Q/10:** Commercially bought from Sigma-Aldrich 49107-U or equivalent.

-Working Haloacetic Acid AQC Standard (10mg/l in MTBE) 23/Q/11: Add 500µl of Stock Haloacetic acid mix (23/Q/10) to a 100ml volumetric flask using an appropriate syringe, then make up to the mark with MTBE. The standard is stable for 6 months stored at 5±3°C.

-Extracted AQC Standard: Measure 50ml of matrix water into a 60ml screw-top vial using a measuring cylinder and add 15µl of 10% Sodium Thiosulphate using an autopipette. Add 50µl of Internal Standard (23/IS/04) using an appropriate syringe, then add 50µl of Working AQC Standard (23/Q/11). This standard should then be extracted as all standards and samples

-AQC blank: Measure 50ml of matrix water into a 60ml screw-top vial using a measuring cyclinder and add 15µl of 10% Sodium Thiosulphate using an autopipette. Add 50µl of Internal Standard (23/IS/04) using an appropriate syringe. This blank should then be extracted as all standards and samples.

Note:
All stock AQC solutions are prepared in house, where possible, using different manufacturer reagents or different production batches to those used in the calibration section of the method. The AQC solutions should be prepared, where possible, by a different analyst to that preparing the calibration standards.

3.4.1.7. Analytical Procedure

HAAs were then measured on a Perkin Elmer Gas Chromatograph Clarus 600C Mass Spectrometer

- ***Gas Chromatograph Conditions***

Column Type 30 metre, 0.25 mm internal diameter, 0.25μm phase thickness DB-5MS or equivalent

Injector Temperature 53^{o}C hold for 0.2 min

Injector Ramp 1 150^{o}C/min to 200^{o}C, hold for 13 min

Injector Ramp 2 10^{o}C/min to 50^{o}C, hold for 0 min

Oven Initial 35^{o}C

Initial Hold Time 2 min

Ramp 1 1.0 ^{o}C/min to 40 ^{o}C, hold for 5 min

Ramp 2 3.0 ^{o}C/min to 74 ^{o}C, hold for 0 min

Ramp 3 40.0 ^{o}C/min to 280 ^{o}C, hold for 2min

Total Run Time 30.48 min

Flow 1.0 ml/min (except at start)

Split Flow 10 ml/min

- ***Auto-sampler Conditions***

Syringe Capacity	5ul
Injection Speed	Normal
Viscosity Delay	0
Pre-injection Solvent Washes	2
Post-injection Solvent Washes (A)	5
Injection Volume	2.5ul
Sample Pumps	6
Wash/Waste Vial Set	1

Pre-injection Samples Washes 2

- ***Mass Spectrometer Conditions***

Source Temperature 200 ^{o}C

Multiplier Voltage 600 Volts (Dependant upon the instrument condition)

Inlet Line Temp 250 ^{o}C

Solvent delay Start 1 0 min

Solvent delay End 1 4.2 min (Dependant upon the instrument condition)

3.4.1.8. Quality Assurance

Standards were run first followed by samples. Blank should have a response less than the detection limit for each HAA. An AQC spike sample and AQC blank must be analysed with each batch of 19 or less samples. All compounds are on single point control charts. And all AQC results must be blank corrected before being plotted onto the AQC control charts.

Calibration Check

Check the correlation coefficient (r^2) for each calibration graph. This must be greater than 0.995 before calibration can be accepted. If the calibration curve does not meet the required 0.995, two standards can be excluded from the calibration curve to attain a coefficient of 0.995 or better. If the upper calibration standard is removed results above new upper range of 30µg/l cannot be reported.

Derivitisation performance

As a possible indicator of the efficiency of the derivitisation reaction, the ratio of 2-Bromobutanoic Acid and 1,2,3-Trichloropropane can be monitored for all samples using the Turbomass software. This is done by processing 2-Bromobutanoic Acid using 1,2,3-Trichloropropane as the internal standard. The concentration of 2-Bromobutanoic Acid must not fall below 7.5µg/l for any sample, this may be indicative of poor derivitisation efficiency and the sample extraction procedure and analysis must be repeated.

System Suitability Check

The area responses for the 23/C/12 of Monochloroacetic Acid and Dibromoacetic Acid used in the first set of calibration standards should be greater than the Lower limits specified: 38894 for MCAA and 7792 for DBAA

Column performance

As the column gets older, the retention time of Monochloroacetic Acid will decrease and move closer to the solvent front. A guideline minimum retention time for Monochloroacetic Acid is 4.5 minutes, after which it may be necessary to replace the column.

Calibration Drift Check

23/C/13 is re-injected as the drift check every 15 samples and at the end of each batch. Results must agree within 15% of the assigned concentration. Allowed limits are 25.5ug/l – 34.5ug/l. A full calibration can be analysed more frequently if there is any indication of instrument drift e.g. after maintenance on the system, periods where the instrument is not in operation.

3.4.1.9. Proficiency Testing:

PT scheme are analysed 4 times a year in order to monitor performance of the method for HAA analysis used. PT samples were purchased from RTC part of Sigma Aldrich and analysed at the same time with the project samples. The PT samples supplied by RTC were of unknown concentration in the range 10-50 μg L^{-1} for six HAAs. The six HAAs were MCAA, MBAA, DCAA, BCAA, TCAA and DBAA.

Compound	Assigned Value	Result	SDPA at 10%	Z score
MBAA	20.1	22.38	2.01	1.13
BCAA	21.7	25.3	2.17	1.66
MCAA	37.1	37.58	3.71	0.13
DBAA	14.8	13.44	1.48	-0.92
DCAA	39.2	45.21	3.92	1.53
TCAA	34	38.73	3.4	1.39

Table 3.7 Proficiency testing results for May 2014

Compound	Assigned Value	Result	SDPA at 10%	Z score
MBAA	17	18.365	1.7	0.80
BCAA	16.2	15.6	1.62	-0.37
MCAA	23.7	26.736	2.37	1.28
DBAA	33.2	32.46	3.32	-0.22

DCAA	37.9	40.484	3.79	0.68
TCAA	37.4	35.361	3.74	-0.55

Table 3.8 Proficiency testing results for March 2014

Compound	Assigned Value	Result	SDPA at 10%	Z score
MBAA	24.2	23.7	2.42	-0.21
BCAA	20.5	21.2	2.05	0.34
MCAA	37.6	36.9	3.76	-0.19
DBAA	38.6	36.6	3.86	-0.52
DCAA	41.1	33.7	4.11	-1.80
TCAA	26.7	27.9	2.67	0.45

Table 3.9 Proficiency testing results for October 2013

Performance Assessment:

Once a PT round has closed, the results will be analysed and the assigned value determined for each analyte, according to the criteria provided in the Scheme Description. Information regarding the traceability of each calculated assigned value is also provided in the Scheme Description.

For quantitative data, the participant's result, x, is converted into a z score using the following formula;

$z = (x - X)/SDPA$

X = Assigned value
SDPA = Standard deviation for proficiency assessment

For the purposes of performance assessment for a single round, z scores are interpreted as follows:

Z score Interpretation:

$|Z| \leq 2.00$ Satisfactory result
$2.00 < |Z| \text{ and } < 3.00$ Questionable result
$|Z| \geq 3.00$ Unsatisfactory result

At Scottish Water we investigate any result that is over +/- 2 Z scores.

3.4.2 THM analysis

The THM concentrations reported were provided by the Scottish Water Organic Laboratories for samples taken on the same sampling day.

A known volume, (5ml), of sample is transferred to a headspace vial. This vial is then heated for a set period of time, (25 minutes), to drive the volatile solvents into the headspace. A portion of the headspace is then injected into a gas chromatograph where the solvents of interest are separated prior to mass spectrometric detection using a capillary column. Quantification of the sample components is done by comparison with external calibration standards and using internal standard correction

3.4.3 Cl_2 residual – free and total chlorine (mg/L)

Measurement of free and total chlorine in potable water is carried out on site using Hach Colorimeter. The free chlorine, under suitably buffered conditions, reacts with a chemical DPD to form a red complex dye. Total Chlorine is a combination of the Free and the Combined Chlorine. The Combined Chlorine is measured (together with the Free Chlorine) by 'releasing' it with potassium iodide to react with DPD and form the complex red dye. The colour produced is proportional to the concentration of chlorine present, and is measured optically by a colorimeter.

3.4.4 Bacterial Analysis – FCM

Flow cytometry (FCM) is used for the quantification of microbial cells in drinking water. Water samples are collected as per routine microbiology sampling techniques however an aliquot of the sample is transferred in to a 50mL centrifuge tube. This becomes the sample for analysis. Further sub-samples of this are taken and transferred in to 2mL micro centrifuge tubes. They are mixed with CYBR Green stain or Propridium Iodide stain. The stained sample is then passed through the Accuri C6 flow cytometer and data is collected and analysied.

3.4.5 Data analysis

For purposes of this study, with HAAs results, THMs total, TOC, pH, total and free chlorine data were analyzed as well. Bromide data also are available but unfortunately bromide was not analysed on the samples taken for HAAs, but on different dates. However, the data should still correlate with the formation of brominated haloacetic acids and THMs. There is no temperature data. Samples values under the detection limit of the methods were assigned the detection limit for statistical analysis. Basic analyses were conducted using spreadsheet calculations (MS Excel) and for more elaborate statistical procedures we used the (free) statistical software R (R Foundation for Statistical Computing, Vienna, Austria).

In order to assess the potential impact of future regulations the data were analysed based on the maximum running average of 60 μg /L.

When calculated the annual average in that study, should not be mixed with the locational running annual average (LRAA) and the running annual average (RAA). Traditionally DBPs are measured at four sites in the distribution system each quarter; three of the sites have average residence times, and one site is at a remote location. The average of each of the four stations is the quarterly average and the average of all four quarters is the annual average. (i.e the average of 16 samples per system) For LRAA the annual average at each of the four sampling sites including the remote location must be below the MCL. Although a large number of samples were analysed over a year, only in 4-6 sampling points HAAs are measured in each distribution system per year and in some distribution zones in even less sampling points.

Chapter 4. Results and discussion

4. Results and discussion

4.1 Four-season occurrence survey of HAAs in Scotland

As mentioned in the literature review there are various operational and water quality parameters that influence the formation of HAAs in chlorinated and chloraminated drinking waters; like the type of disinfection scenario, water treatment process, nature of water source, bromide content, pH of chlorination and distribution, temperature, concentration of total and free chlorine, residence time, distribution system characteristics, levels of total organic carbon (TOC) [1, 3, 9, 11].In this chapter we will investigate how most of these factors influence the occurrence and speciation of HAAs in the distribution zones of Scotland, determine the behaviour of HAAs in the different water distribution systems monitoring differences between zones and variations throughout seasons.

All information used in this chapter, about the type of disinfection method, the type of water source, the population served and water treatment stages of each WTW, is reported in Tables 7.2 and 7.3 of the Appendices.

During the period under investigation, a total of 1615 samples were collected for all distribution zones. The statistical summary of water quality parameters distribution samples is presented (Table 4.1). These parameters are studied because they may have an impact on HAAs concentrations. They give an indication about the presence of HAAs precursors, but also describe the environment present in the distribution system that will promote or suppress the formation of HAAs.

Quality Parameters

All samples had the following range of concentrations:

Table 4.1 Quality parameters of water samples from the distribution system

	Bromide (µg/L)	TOC (mg/L)	pH	Free Cl_2 (mg/L)	Total Cl_2 (mg/L)
Q1	7	0.5	7.6	0.11	0.35
Minimum	7	0.2	6.7	0.03	0.03
Median	7.8	0.8	7.9	0.32	0.53
Maximum	519.3	5.6	9.6	1.20	1.69
Q3	17	1.3	8.2	0.51	0.73

Mean	22.12	1.00	7.94	0.34	0.56
Std	46.54	0.70	0.44	0.24	0.28

Unforunately bromide was not analysed on the samples taken for HAAs, but on different dates.
The relatively high level of bromide was measured mostly in zones located in islands or areas close to the sea. A reason may be that the source is located near sea coastline and therefore, usually there is a sea water intrusion to this water source.

Table 4.2 Seasonal variation of quality parameters of water samples from the distribution system

	Autumn				Winter					Spring					Summer				
	TOC (mg/L)	pH	Free Cl_2 (mg/L)	Total Cl_2 (mg/L)	TOC (mg/L)	pH	Bromide (µg/L)	Free Cl_2 (mg/L)	Total Cl_2 (mg/L)	TOC (mg/L)	pH	Bromide (µg/L)	Free Cl_2 (mg/L)	Total Cl_2 (mg/L)	TOC (mg/L)	pH	Bromide (µg/L)	Free Cl_2 (mg/L)	Total Cl_2 (mg/L)
Q1	0.5	7.7	0.12	0.29	0.5	7.6	7	0.17	0.39	0.5	7.7	7	0.16	0.39	0.3	7.8	7	0.08	0.29
Minimum	0.5	6.9	0.03	0.03	0.5	6.7	7	0.03	0.09	0.2	6.9	7	0.03	0.04	0.2	6.8	7	0.03	0.03
Median	0.9	7.9	0.28	0.46	0.7	7.7	9	0.36	0.58	0.7	8	7.2	0.36	0.55	0.8	8	10.15	0.25	0.48
Maximum	5.6	9.1	1.11	1.69	3.6	9.1	519.3	0.92	1.47	2.9	9.6	376.3	1.17	1.41	5	9.2	176	1.20	1.41
Q3	1.8	8.125	0.49	0.71	1.2	8	14.15	0.54	0.78	1.2	8.25	16.775	0.53	0.73	1.4	8.3	29.175	0.46	0.68
Mean	1.24	7.93	0.33	0.52	0.95	7.78	21.17	0.37	0.60	0.92	8.00	21.12	0.36	0.58	0.98	8.05	27.70	0.30	0.51
std	0.85	0.43	0.24	0.29	0.60	0.39	56.44	0.23	0.26	0.53	0.44	43.66	0.23	0.27	0.82	0.42	37.11	0.24	0.29

Water temperature data are not available however information from http://www.metoffice.gov.uk [61] show winter average temperatures from - 4 to 7 °C, with summer averaging 6 to 15.5 °C, spring -1 to 9°C and autumn 1-11°C. In general, the western coastal areas of Scotland are warmer than the east and inland areas, due to the influence of the Atlantic currents.
In the current study TOC levels were also measured. TOC can be considered as an indicator of the levels of NOM and therefore organic HAA and THM precursors present in water, even if that is not exhaustive [34]. A higher TOC levels is likely to produce more THMs and HAAs [11].
It is important to check the seasonal variations of these parameters because they can explain the seasonal variations of HAAs concentrations. HAAs seasonal variations are influenced by variations in water temperature, the amount and type of NOM, raw and treated water quality parameters during the year, and operational parameters (e.g. chlorine dose, pH adjustments) during treatment, which are the response to these water changes [34]. As shown in Fig. 4.1 an increase in TOC concentrations was observed in summer and autumn, as during these months drinking water had the widest range of TOC concentrations, as well the highest median and highest maximum levels compared to the other seasons. That was expected as watersheds during winter are covered by an ice layer and the organics are immobilised. Furthermore during cold months the microbial activity is minimal.

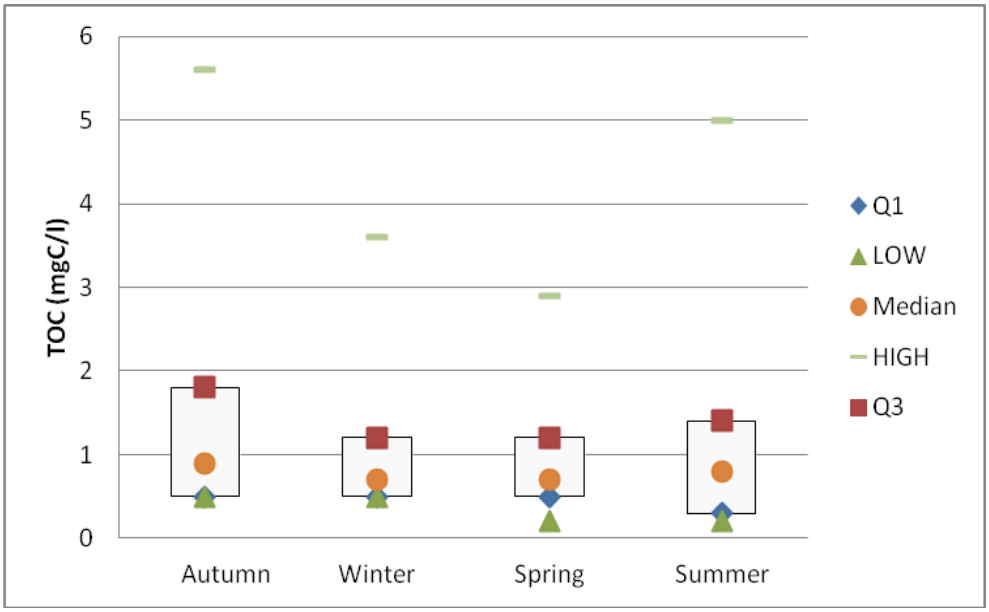


Figure 4.1 TOC seasonal variations

In addition during winter and spring higher concentrations of free and total chlorine were measured in the distributed water, compared to the other seasons, even if during the warm seasons we expect to have higher chlorination doses (data not available). The losses of chlorine residual in the summer and autumn are primarily due to bacterial growth in storage tanks and distribution lines. Furthermore during warm months when higher temperatures occur, chlorine consumption by the pipes and reaction with substances in the bulk water like NOM is promoted [16]. pH values did not vary significantly during the four seasons.

Presence and Speciation of HAAs

The individual and total HAA5 levels and the total THM levels found in our study are reported (Table 4.3). Average HAA5 in distribution systems were about 50% lower than total THMs.Compared with a previous study undertaken by Malliarou et al. (2005) in the UK where a mean concentration of total HAA6 was ranging from 35.1-94.6 (μg/L) and a maximum concentration of 244 (μg/L) was observed, the total HAA5 concentrations reported in this study were relatively low (median value of 11.45 μg/L , with a maximum value of 150.4 μg/L and a minimum value <5.3 μg/L) Our results had lower median concentration compared with a more recent study carried out by Zhang et al. (2011) in one utility system in England and its distribution network, where the levels of HAA9 were ranging from 11.1-20.6 μg/L with a maximum value of 41 μg/L. However, our maximum HAA5 concentration was much higher compared to that study. Moreover our results come from 298 distribution zones not only from one zone.
Furter to this, one study carried out by Goslan et al. (2009) in Scotland showed median HAA_9 concentration of 20 μg/L and more recently the same group carried out a study [59] about the occurrence of HAA_9 measured in final samples of 9 WTWs of England on a seasonal basis and found levels ranging from 0.3-28.9 μg/L but overall the median value was 12.5 μg/Lwhich is higher than that observed in our study.

Table 4.3 Individual and total HAA and total THM levels (μg/L)

	TCAA (μg/L)	DCAA (μg/L)	BCAA (μg/L)	DBAA (μg/L)	MCAA (μg/L)	MBAA (μg/L)	HAA_5 (μg/L)	THM_4 (μg/L)
Q1	1.40	2.20	0.90	1.10	1.00	0.80	6.00	12.10
Minimum	1.10	1.30	0.90	1.10	1.00	0.80	5.3	3.20
Median	5.30	4.50	1.20	1.10	1.00	0.80	11.45	24.50
Maximum	82.00	65.70	22.90	34.30	3.70	5.30	150.40	153.20
Q3	10.00	8.70	2.20	1.30	1.00	0.80	19.40	43.80
Mean	7.53	6.50	1.94	1.68	1.06	0.85	15.47	30.77
Std	8.29	6.17	1.76	2.14	0.23	0.24	13.29	24.14

During the period of study among HAA_5, DCAA and TCAA were the main species where the sum of these two species represented over 83.1% of the total HAA_5 (41.2 % and 41.9 % respectively). Other studies in the UK (Malliarou et al. 2005, Zhang et al. 2011, Goslan et al. 2009) show the same and studies in Canada and Finland [3,6, 40] agree as well. Generally non-brominated HAAs dominated in the waters of the distribution zones under study.

Figure 4.2 shows the distribution of HAA_5 in the different regions of Scotland. On a median basis distribution zones located in the North region of Scotland exhibit the lowest concentrations while regions in the South the highest, but the differences are not that pronounced amongst the different regions (see Appendice Table 7.4)

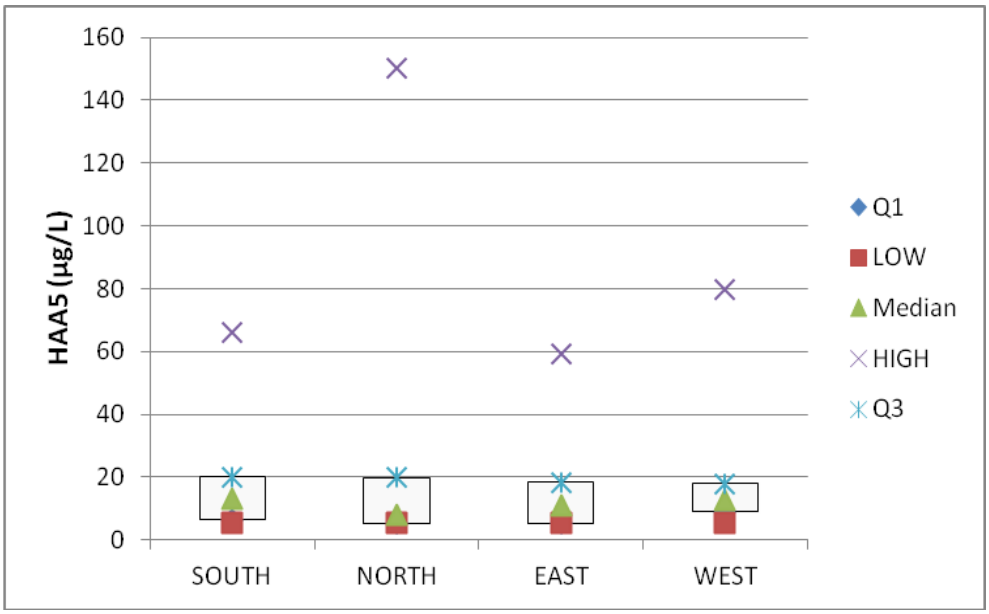


Figure 4.2 Distribution of HAA5 in different regions of Scotland

Furthermore (as is noted in Figure 4.3) most systems comply with the maximum acceptable concentration limit set for the US (60µg/L). In the study by Zhang et al. (2010) no samples were observed that had HAA_9 concentrations greater than the USEPA standard, 60 µg/L, or the proposed EU standard of 80 µg/L, however in the Goslan et al. (2009) study the chloraminated samples never exceeded the proposed EU standard but the chlorinated samples often exceeded it. We have to bear in mind that from 2009 until today many WTWs in Scotland have changed their water treatment processes in order to comply with the THMs regulations by reducing DBPs precursors.

In 0.7% of the zones under study, the average HAA_5 concentration exceeds 60µg/L. The plants with a mean HAA_5 concentration higher than 60µg/L were small systems with a service population less than 3300 people. The chart below also shows that the average concentration of HAA_5 varies significantly based on the population served by a network. This trend, however, is not so clear. What we can say with certainty is that the very small WTW (<500 people) appears to have the lowest concentration of HAA_5, on a median basis. The highest median concentration of HAA_5 appears in networks of 500-3300 residents where it is also the widest range of concentrations. These low concentrations of HAAs are due to the fact that most systems in large cities tend to implement more effective DBP control strategies and the NOM has been efficiently removed [17]. The high levels found are thought to be due to the non-optimized removal of organics at these works.
Similar trends were found for the total THMs (Figure 4.4) with only one zone experiencing higher concentration than the regulatory limits (100µg/L). However that

result comes only from one sample measurement during September and it may not be representative of the THMs concentrations of that zone.

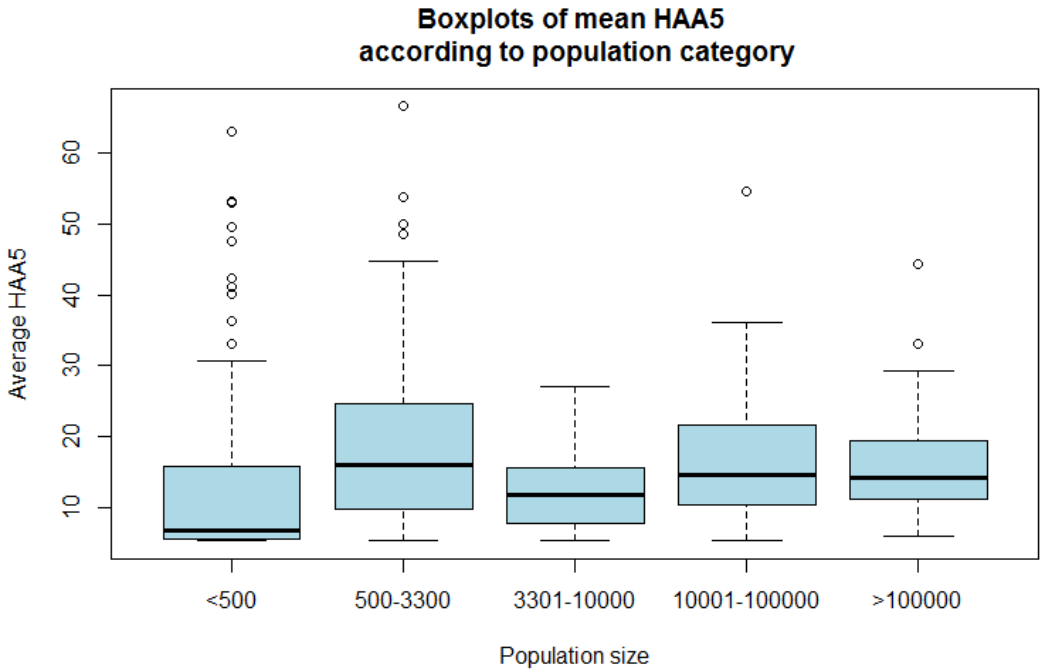


Figure 4.3 Annual average HAA5 (µg/L) according to population category

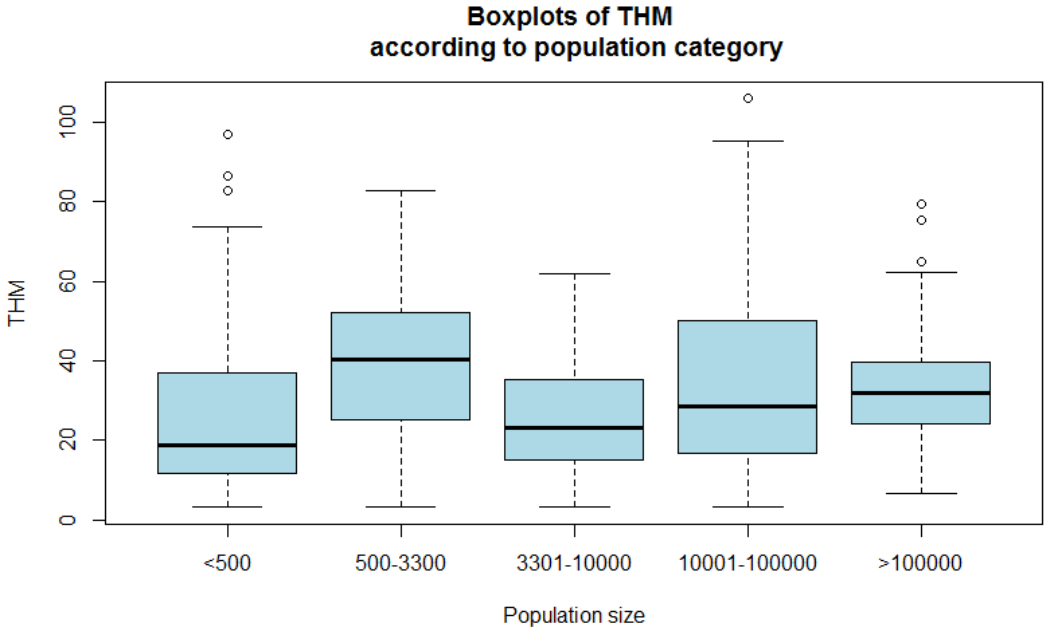


Figure 4.4 Annual average THMs total (µg/L) according to population category

Furthermore there is a very weak correlation between the population served and the annual average HAA_5, and between the population and the annual average THMs total.The Spearman correlation coefficients (r_s) were 0.25 and 0.15 respectively.

We used the non-parametric Spearman correlation test due to the lack of symmetry in the corresponding histograms (Figures 7.1 and 7.2 in Appendices).

HAAs formation is strongly dependent on the type of water source (surface or ground water) and the type of water treatment and disinfection used [34].

Water suppliers use a variety of treatment processes to remove contaminants from drinking water. The most commonly used processes include coagulation/flocculation and sedimentation/clarification and/or filtration, and disinfection for surface water [38]. The coagulation step removes substantial amounts of DBP precursors and shifts the distribution of HAA and THM species. Chlorinated DBPs precursors can also be minimised by oxidation (the use of ozone, for example), by membrane filtration processes and by activated carbon absorption (GAC) [38]. Combination processes have also emerged to deal with DBPs precursors like micro or ultrafiltration membranes combined with coagulation and ozone/biofiltration [2].

From the data gathered from Scottish Water (see Tables 7.2 and 7.3 of the Appendices and figures 7.3,7.4, 7.5, 7.6, 7.7) we can see that in Scotland WTWs serving less than 500 inhabitants (in total 110) the majority are using membrane filtration or another type of filtration (or combination of them) like GAC filters. Membrane filtration units are installed in relatively small facilities because they provide a barrier to Cryptosporidium and can be fully automated.
Eleven WTWs have HAAs average concentrations >30 μg/L. These WTWs have at best only simple treatment prior to chlorination. Eight WTWs produce their water from surface water and two of them were membrane works, five used GAC filtration (one of them had average HAA concentration >60 μg/L) and one used a combination of GAC and RGF (Rapid Gravity Filtration) filtration. The rest were ground water WTWs that only disinfect their waters.

Twenty-one percent of WTWs serving less than 500 inhabitants are supplied by ground water and represent 69% of the total WTWs that use ground water. When ground water is used the treatment is minimal consisting only of chlorination most of the times. Groundwater tends to be relatively clean (and low in organics) in comparison to surface water, and fewer treatment steps are required.
Thus the low HAA concentrations detected in the zones supplied by these WTWs are due to the use of membrane filtration and the fact that many WTWs produce their water from ground water.

As the size of WTW increases membranes are less used and the most common treatment stage for the removal of NOM is coagulation-flocculation followed by filtration or coagulation-flocculation followed by clarification/sedimentation and filtration or by flotation and filtration sometimes.
For the utilities serving 500-3300 (50 in total) inhabitants coagulation-flocculation is the most common treatment stage followed by filtration (Pressure filters, RGF). Sometimes flocculation is combined with flotation followed by RGF or

clarification/sedimentation followed by flitration (Pressure filters, RGF). Less WTW use membrane treatment and even less GAC filters.
Here eight WTWs have HAAs average concentrations >30 μg/L. All of them were surface water WTWs. Half of them (one exceeded the 60 μg/L) were membrane WTWs, one GAC, one combination of pressure filtration and GAC, one flocculation-clarification-pressure filtration and one flocculation-pressure filtration.The interesting thing is that although one WTW used flocculation-flotation-RGF and chloramination for disinfection, it had average HAA_5 concentrations close to 50 μg/L
For the utilities serving 3301-10000 (25 in total) inhabitants coagulation-flocculation again is the most common treatment process followed by RGF. Sometimes flocculation is combined with flotation before filtration or with clarification/sedimentation.
Here none of the WTW experienced HAAs average concentrations >30 μg/L

Similarly for the WTWs with 10001-100000 population and >100000 the most common treatment stage is coagulation-flocculation followed by RGF. Sometimes flotation is used before filtration or clarification/sedimentation.
Here in total only 5 WTWs had HAAs average concentrations >30 μg/L
One is a membrane WTW and is the only one that uses ground water, three use flocculation-flotation-RGF and one GAC-ozonation. However many studies has stated that ozonation causes low molecular weight organic matter fractions in water, which are HAAs precursors. Thus their chlorination leads to the formation of HAAs [12].

Even if the removal of HAAs in GAC filters has been reported [2] as another cost effective DBP control startegy, there are some WTWs with concentrations relatively high and one of the WTW that exceeded the 60 μg/L uses GAC.
However we cannot make conclusions about which WTW experienced the higest HAA concentration and why because we do not have all the desired information like raw water amount and characteristics. For example two WTWs may have the same water treatment procedure but different HAAs concentrations on the distributed water. One possible explaination is that maybe the water with the higher HAA concentration had raw water with high aromaticity (UV-254). Furthermore we do not know the operational parameters that influence HAA formation like the chlorine dose of each WTW, neither the chlorination pH and contact time.
Furthermore the situation is constantly changing as WTWs are trying to lower their DBPs levels. In many WTWs in Scotland enhanced coagulation and ultra membrane-coagulation has been introduced in order to reduce the level of NOM in the water and comply with the THMs regulations. Furthermore future strategies for the future include:

- Catchment management / different sources
- Better analysis techniques (organics fractionation)
- On-line UV254 measurement
- Membrane Installation / refurbishment
- Disinfection optimisation
- Filtration performance curves
- GAC polishing units
- Chloramination
- Aeration

Notwithstanding it is difficult to identify the operational conditions that are optimal for reducing DBPs occurence, reducing operational costs, all the while ensuring adequate microbial inactivation levels.

We detected also differences in HAAs levels by type of source water and disinfectant used.

Table 4.4 HAA_5 (µg/L) concentrations according to water source and disinfection strategy used

	Ground Water HAA_5 (µg/L)	Surface Water HAA_5 (µg/L)	Chloraminated Water HAA_5 (µg/L)	Chlorinated Water HAA_5 (µg/L)
Q1	5.30	7.00	5.78	6.00
Mininum	5.30	5.30	5.30	5.30
Median	5.30	12.35	9.60	11.90
Maximum	74.30	150.40	59.10	150.40
Q3	7.15	20.13	16.20	19.90
Mean	9.73	16.31	13.04	15.95
Std	10.39	13.55	10.04	13.81

When water type is considered , it is shown that ground water produces lower levels of HAAs than surface water (Fig. 4.5, Table 4.4) The results agree with several other studies that found that ground water supplied systems experienced very low levels of total HAAs [9,5,24]. Surface reservoirs or river waters have relatively high TOC levels and are influence by algal blooms.The groundwater tends to contain less NOM and hence less potential to form DBPs [9].
As shown (Table 4.5) lower TOC concentrations were detected in ground water supplied zones and this is one explanation of the higher HAAs concentration from the surface water supplied zones .

Table 4.5 TOC (mg/L) levels acccording to water source

	Surface Water TOC (mg/L)	Ground Water TOC (mg/L)
Q1	0.50	0.50
Minimum	0.20	0.20
Median	0.80	0.50
Maximum	5.60	3.30

Q3	1.40	0.60
Mean	1.06	0.66
Std	0.71	0.50

In the water treatment works using ground water in most of the cases, the treatment involves just chlorination using usually hypochlorite. Only one of the 39 WTWs chloraminates the treated water. Only six of them use membrane treatment and only four use filtration before the disinfection stage. The highest concentrations of HAA_5 were detected in the distribution zones where water was only chlorinated, with one exception of a membrane treatment work called Howden. The samples of distributed water show concentrations of HAA_5 average 36.4 μg/L with TCAA and DCAA being the dominated species as low bromide concentrations were detected (9.2 μg/L**)**. These higher concentrations compared to other zones supplied by ground water, could be due to a number of reasons.For example the average TOC concentrations of 1.2 mg/L may explain the higher HAAs concentrations and the relatively high chlorine residual detected ranging from 0.37-0.85 mg/L free chlorine. Such a residual concentration has been found to inhibit HAAs degradation (Baribeau et al., 2006). Furthermore high concentrations of NOM in the source water at the point of disinfection or high chlorine dose or/and increasing contact time could be a reason. However without a specific investigation into the water treatment and distribution zone the reasons are not clear.

Zhang et al. (2010) in an utility system of England that uses ground water found very low HAA_9 levels with average and maximum concentrations of 0.6 and 1.9 μg/L respectively. In that study BCAA and DBAA were the dominant HAA species and both were present at relatively low concentrations. However in our study for the total of systems supplied by ground water DCAA and TCAA were the dominant species. Figure 4.6 (see also Table 7.5 in Appendices) shows the speciation of HAAs in surface water and ground water supplied zones. In both cases DCAA and TCAA were the dominant species but their concentrations were higher in surface water supplied zones. MCAA and MBAA were both in most of the cases below their detection limits. BCAA was a little bit higher in surface water supplied zones and DBAA was a slightly higher in ground water supplied zones.
The combination of low levels of NOM and high bromide levels, characteristics of many ground water sources would lead to a higher proportion of brominated HAAs formed [36]. Though is not the case in our study. This is likely because the bromide concentrations are not very high (75% of the values are less than 0.047mg/l) in the distributed water. When the bromide concentrations in raw water is very low (<0.1 mg/L) it has been shown that DCAA and TCAA are the major DBPs in treated waters [56]. Unforunately we do not have data about the bromide concentrations of raw water.

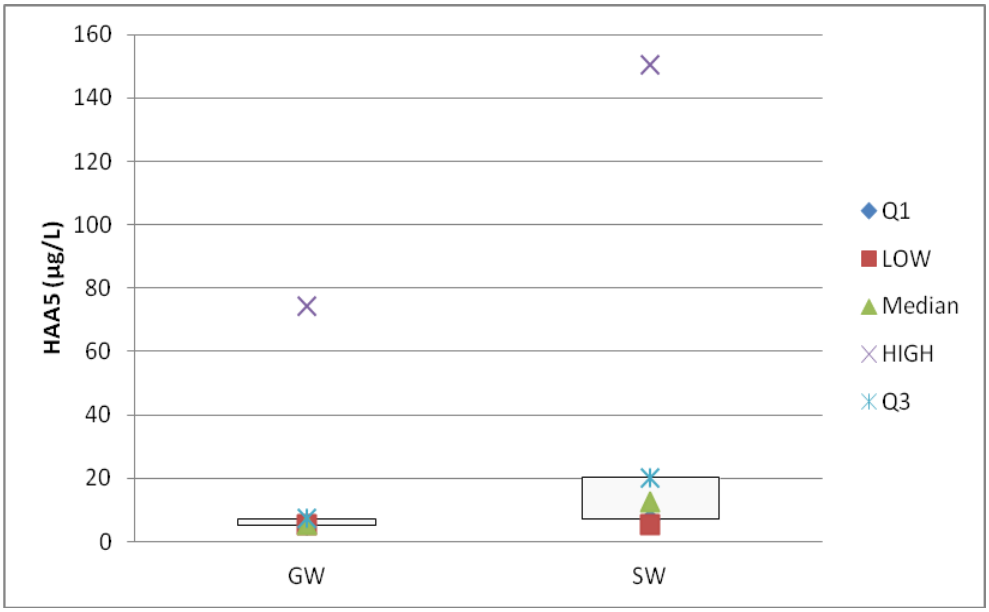


Figure 4.5 HAA_5 distribution according to water source (SW:surface, GW: ground water source type)

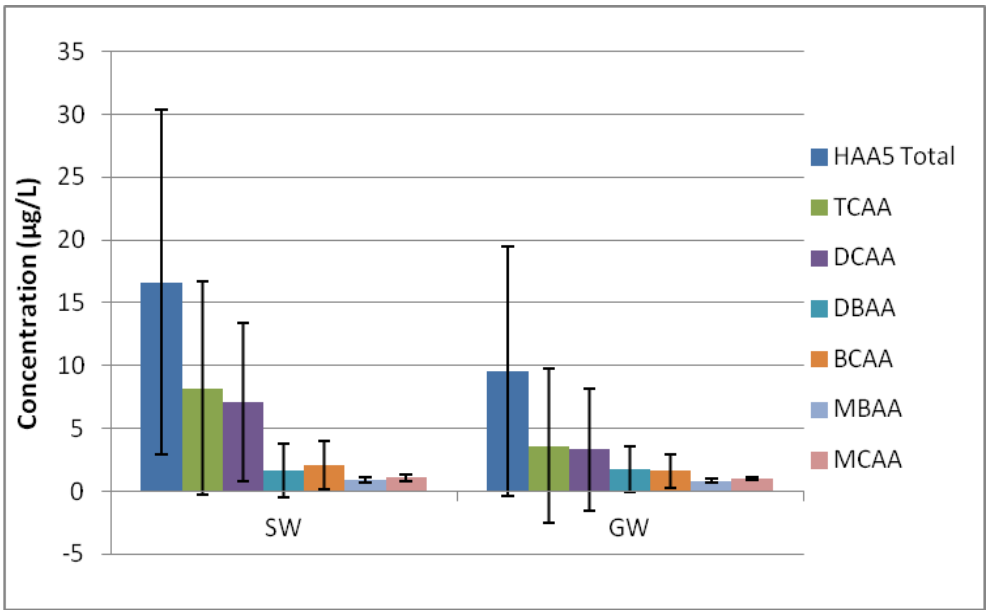


Figure 4.6 HAAs speciation according to water source (SW: surface water, GW: ground water)

The bromide concentrations are higher in the ground water supplied zones compared to surface water supplied zones.

Table 4.6 Comparison of Bromide concentration according to water source

	Surface Water Bromide (μg/L)	Ground Water Bromide (μg/L)
Q1	7.00	14.23
Minimum	7.00	7.00
Median	7.50	24.15
Maximum	519.30	365.70
Q3	14.48	47.75
Mean	19.05	45.51
Std	41.69	73.96

The bromine-containing DBPs are considered to be more harmful than chlorine containing compounds [4, 47], but in this study the brominated compounds were found in very low concentrations compared to the other HAAs species. Malliarou et al. (2005) in their study in the UK found as well that brominated HAA levels were lower. Only in two zones DBAA was found in a concentration ranging between 21-34.3 μg/L. One of the zones is the zone which had the maximum concentration of bromide and the other two had a very low bromide concentration (7 μg/L). In all the other zones DBAA concentrations were much lower.
In addition only in one zone BCAA was found in concentrations ranging between 20.5 and 22.9 μg/L.Unfortunately there is no available data on the bromide concentration of that zone. In the rest of the zones BCAA concentrations were much lower. These results can be explained by the low levels of bromide ion in the distributed water, which lead to a low concentration of brominated HAAs.

The use of HAA_5 is a limitation of our study because we are not able to examine the HAA_9 mixture and the proportion of brominated HAAs species.Furthermore HAA_9 levels can be 20-50% higher than HAA_5 levels in high bromide concentration of the chlorinated water [2, 8, 20, 25].

The HAA_5 distribution according to the disinfection practice is shown (Figure 4.7, Table 4.4) for the different treatment works of the study. On a median basis although the chloraminated waters have lower HAA5 levels compared to chlorinated waters, the difference between chrorinated and chloraminated waters medians is not that pronounced. Moreover all the works using chloramination meet the USEPA HAA_5 maximum contaminant limit whereas some chlorinated samples exceeded it.
Chloramination is shown to control the formation DBPs in the distribution system, however maybe the 30 minutes contact time of free chlorine at the work before ammonia is added is sufficient to form high levels of THMs and HAAs[4].

The significant impact of chloramination on HAAs speciation has been reported. Dihalogenated and trihalogenated HAAs are generally in equal levels in chlorinated water but dihalogenated HAAs are always the dominant group detected when using chloramination [4]. Therefore as we can see (Figures 4.8 and 4.9) the results of this survey agree with the literature (see also Table 7.6 on Appendices)

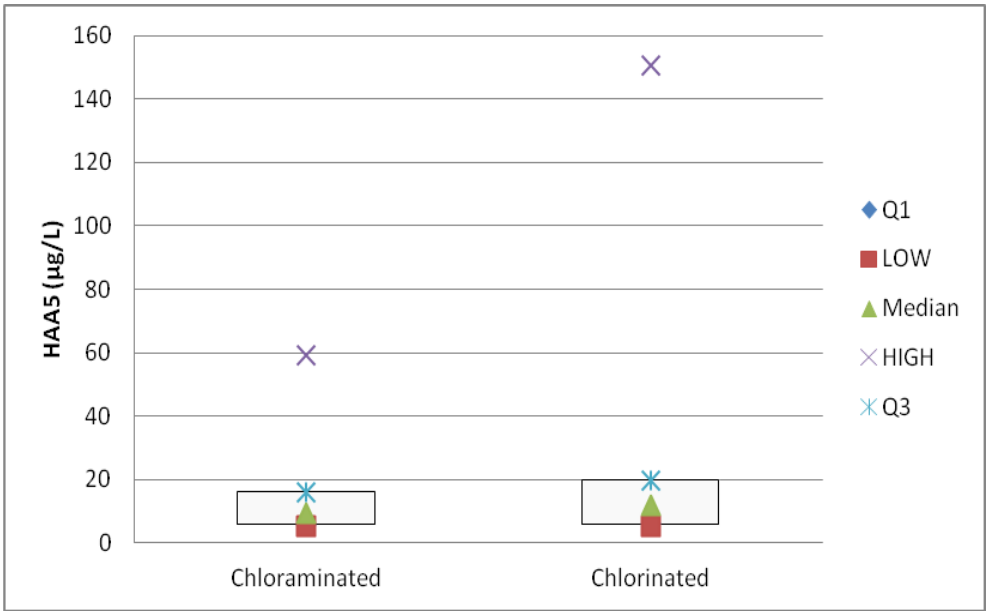


Figure 4.7 HAA_5 distribution according to disinfection strategy used

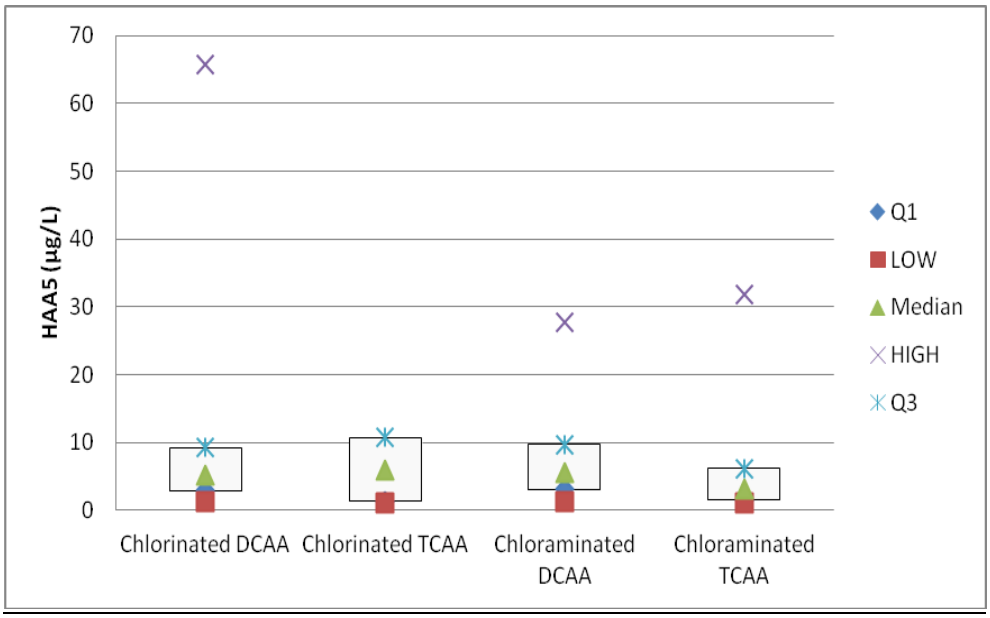


Figure 4.8 Distribution of DCAA and TCAA between chlorinated and chloraminated zones

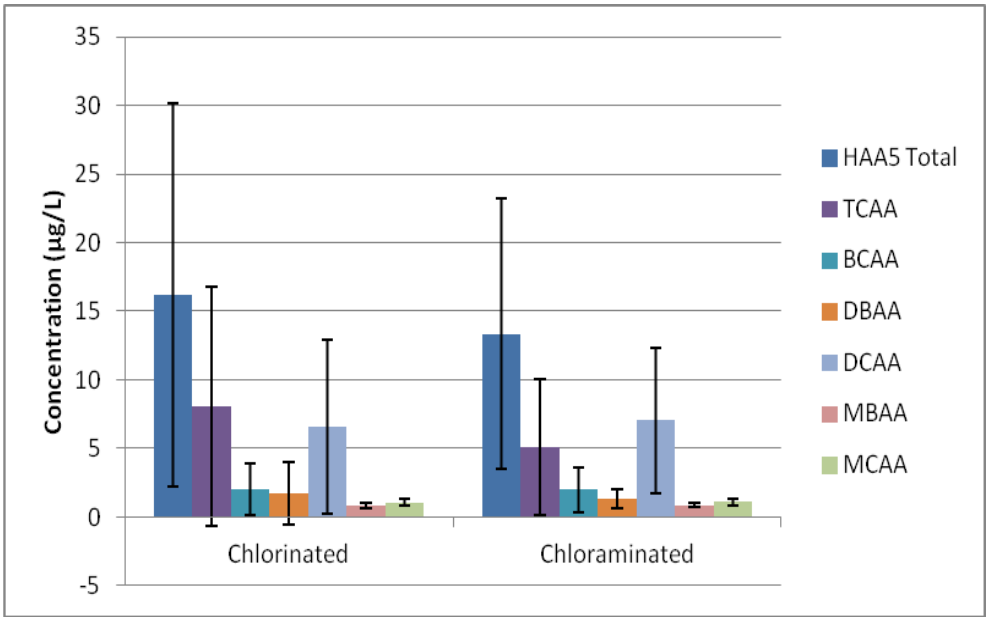


Figure 4.9 HAAs speciation according to the disinfection strategy used

Although chloramines reduce the levels of HAAs and THMs, it is not clear yet their impact on the formation of many other DBPs. It has been shown that chloramination increases the concentrations of other DBPs like certain nitrogenous DBPs that may be more cytotoxic and genotoxic than THMs and HAAs [4, 42].

HAAs seasonal variation

Many full-scale and bench-scale studies are available regarding the seasonal and spatial variations of THMs and HAAs in the distribution systems of several regions around the world such as the U.S.A, Canada, Australia, Taiwan, China, France, England and Turkey [6, 12, 20, 22, 24, 36, 43, 46]. In most of the studies THMs concentrations were higher during summer, but HAAs seasonality is less well defined [22]. In Canada the seasonal variations were very pronounced and the highest HAAs concentrations were measured during summer and spring and for THMs summer and autumn [34]. Though in Turkey a study showed higher HAA_9 average concentrations in spring and autumn and lowest during summer. Similarly a Chinese study found similar results to the Canadian study. A study in Taiwan showed higher HAA_5 during summer [22]. In Scotland a study by Goslan et al. (2009) found higher HAA_9 concentrations during summer as well and lower during spring and winter.

The seasonal variation of HAA_5 in water distribution systems of Scotland is presented (Table 4.7, Fig. 4.10). The median data show some seasonal variations, however this is not as pronounced as in other published studies in the U.S and Canada. The highest median and the widest range of HAA_5 concentrations were observed in autumn and summer (13.2 and 10.4 respectively) while the lowest were obtained in winter and spring season (10.4 and 9.7 respectively).During autumn and summer, concentrations of HAAs ranged from <5.3-85.6 µg/L and <5.3-150.4 µg/L respectively. This is possibly because the water temperature is higher in summer and autumn, promoting the formation reactions of HAAs and THMs. Furthermore more DBPs precursors may

be present, because higher TOC levels were also observed during summer and autumn (Table 4.2). Unfortunately we don't have data about the chlorination doses during treatement but we assume that during the warm months the chlorination doses are the highest to combat the increased rate of microbial growth during the warm months [1].

Table 4.7 Seasonal variation of HAA5 in all distribution zones

	HAA5 (µg/L) AUTUMN	HAA5 (µg/L) WINTER	HAA5 (µg/L) SPRING	HAA5 (µg/L) SUMMER
Q1	8.1	5.625	5.3	7.1
Minimum	5.3	5.3	5.3	5.3
Median	13.2	10.35	9.7	14.5
Maximum	85.6	82.9	91.6	150.4
Q3	23.1	15.275	15.675	25.8

One possible explaination for some high winter HAA concentrations is that during winter there is less water demand so low plant flow. Therefore there may have been longer detention time in service reservoirs and longer free chlorine contact time [4]. Furthermore higher concentrations of free and total chlorine were detected in the distribution system during winter and spring as well. These higher chlorine concentrations have been shown to suppress microbial degradation (Baribeau et al., 2006) in addition to microbial activity being lower at lower temperatures.
The seasonal pattern of HAAs formation was similar to that for total THMs, with a seasonal variation more pronounced in comparison to HAAs. During autumn and summer the THMs total concentrations were ranged from 3.2-131.7 µg/L and 3.2-153.2 µg/L respectively.
We could also assume that during the warm months there is a greater degradation of HAAs along the distribution systems, explaining the less pronounced seasonal variation of HAAs and the more pronounced seasonal variation of THMs, which do not degrade along the distribution system [3].
As mentioned in the literature review the seasonal variations of DBPs and therefore of HAAs are related to changes in NOM quantity and characteristics of water sources and consequently variations in operational parameters concerning the disinfection. The climate of Scotland is temperate and tends to be very changeable, but not normally extreme. The changes between summer and winter are generally relatively moderate, rather than extreme hot or cold. Hence maybe in our study the seasonal changes in surface water quality and water temperature are not as extreme in countries such as Canada over the year and do not necessitate large operational variations in water treatment.

The seasonal portrait presented herein is similar to that observed in other regions in the UK [24] and Scotland [4], and different from that observed in other regions of the world like Canada, Turkey and China [22].
However it is better not to compare the seasonal variation of HAAs between studies in different part of the world because variations in water quality depend on climatic conditions that are specific to each region of the world (temperature, precipitation etc.) [6]. Furthermore there is a limitation comparing data from previous studies; the use of different HAA metrics. Some studies used HAA_5, others HAA_6 and some others HAA_9 [20, 22].

Table 4.8 Seasonal variation of THM4 in all distribution zones

	THM_4 (µg/L) AUTUMN	**THM_4 (µg/L) WINTER**	**THM_4 (µg/L) SPRING**	**THM_4 (µg/L) SUMMER**
Q1	17.1	8.2	10.825	17.55
Minimum	3.2	3.2	3.2	3.2
Median	33.8	18	22.25	32.9
Maximum	131.7	104.4	103.4	153.2
Q3	51.5	28.4	40.125	55.35

The highest measured level of HAA_5 during the survey was 150.4µg/L during summer in the chlorinated distribution system supplied by Lochaline works.
Generaly the higher concentrations of HAAs (average HAA_5>50 µg/L) were detected in six chlorinated zones supplied by surface treated water.Five of them were located in the North region and the other one in the East region. Furthermore the five zones serve <3,300 habitants. Two of them are membrane works, four use GAC filters and one ozonation before and after filtration. All of them had TOC average concentrations raging from 0.9-2.4 mg/L.

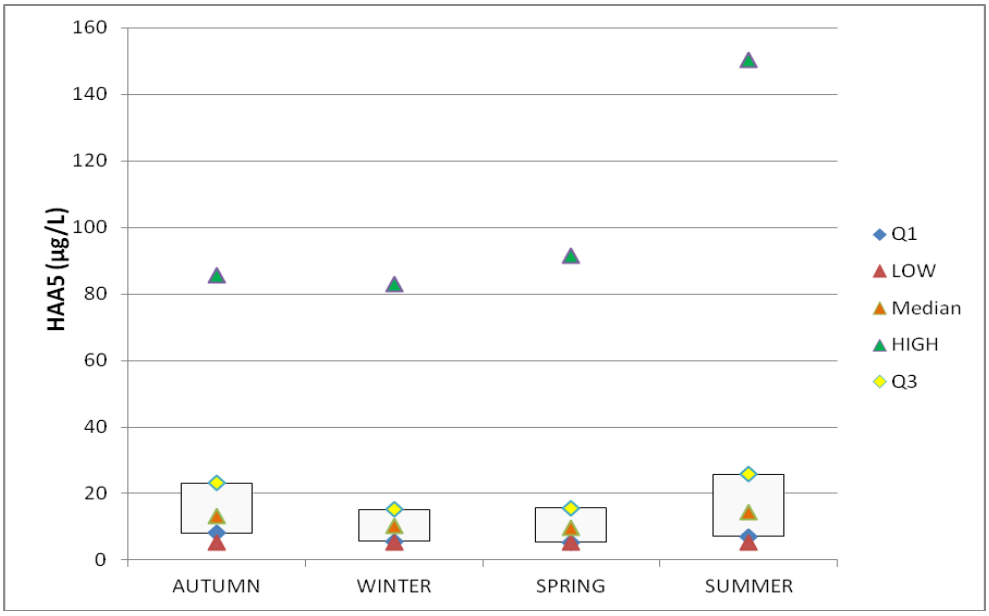


Figure 4.10 HAA5 seasonal variation for all zones

As we can see (Figures 4.11, 4.12, 4.13, 4.14) there is no seasonal variation in HAAs for the ground water supplied zones and the seasonal variation for the chlorinated zones is more pronounced compared to chloraminated zones. There is a higher increase of HAA_5 during summer in the chlorinated zones (see also Appendices table 7. 7, 7.8)

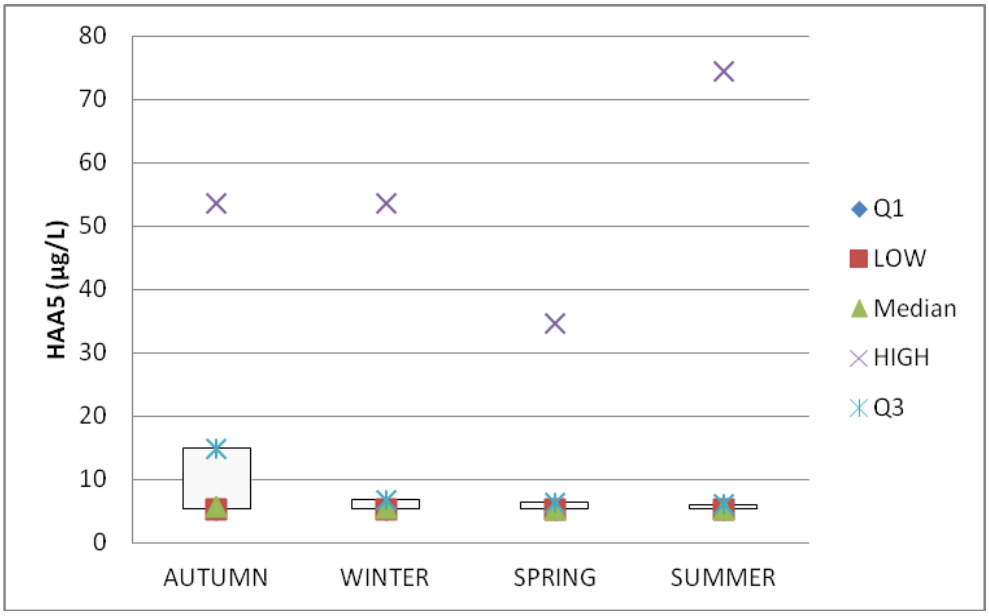


Figure 4.11 HAA5 seasonal variation for GW supplied zones

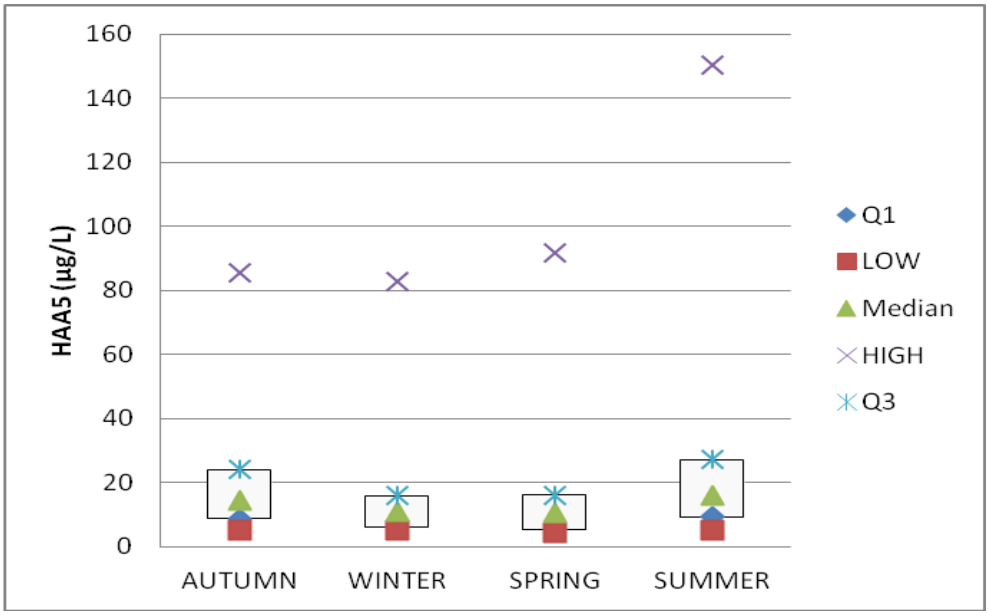


Figure 4.12 HAA5 seasonal variation for SW supplied zones

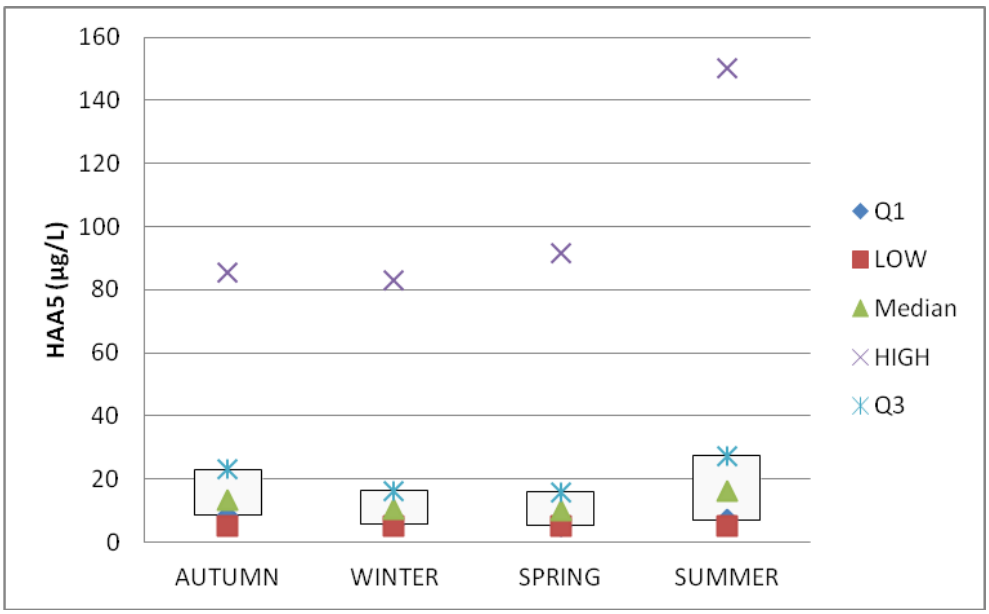


Figure 4.13 HAA5 seasonal variation for Chlorinated zones

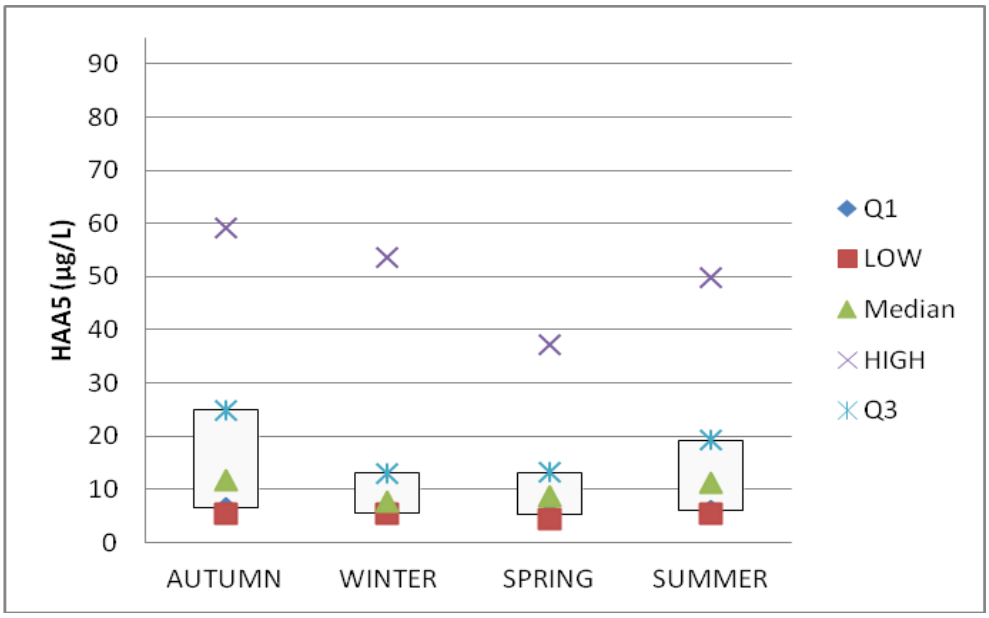


Figure 4.14 HAA_5 seasonal variation for Chloraminated zones

In addition the behavior of DCAA and TCAA are not the same during seasons.
The median data show almost no seasonal variation for the DCAA however the seasonal variation of TCAA is more pronounced and higher concentrations were detected during summer and autumn**.** A possible explaination is the degradation of DCAA in warm waters due to the presence of biofilm into the distribution system [3].
The analysis of HAAs fate according to location will allow better observation of HAA biodegradation.
Another explaination could be that NOM characteristics change over the year. There is a shift not only in the quantity but also in the composition of NOM during the year, and as we know DCAA and TCAA have different precursors [3].

Similarly with DCAA there is no seasonal variation for BCAA and DBAA (see figures below and Table 7.9 in the Appendices).

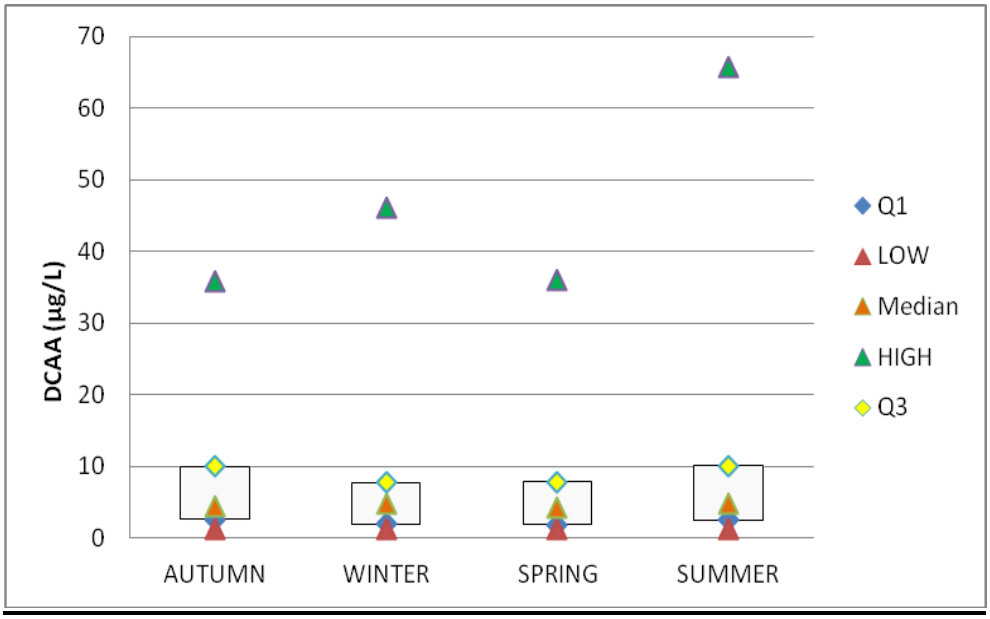


Figure 4.15 DCAA seasonal variation for all the zones

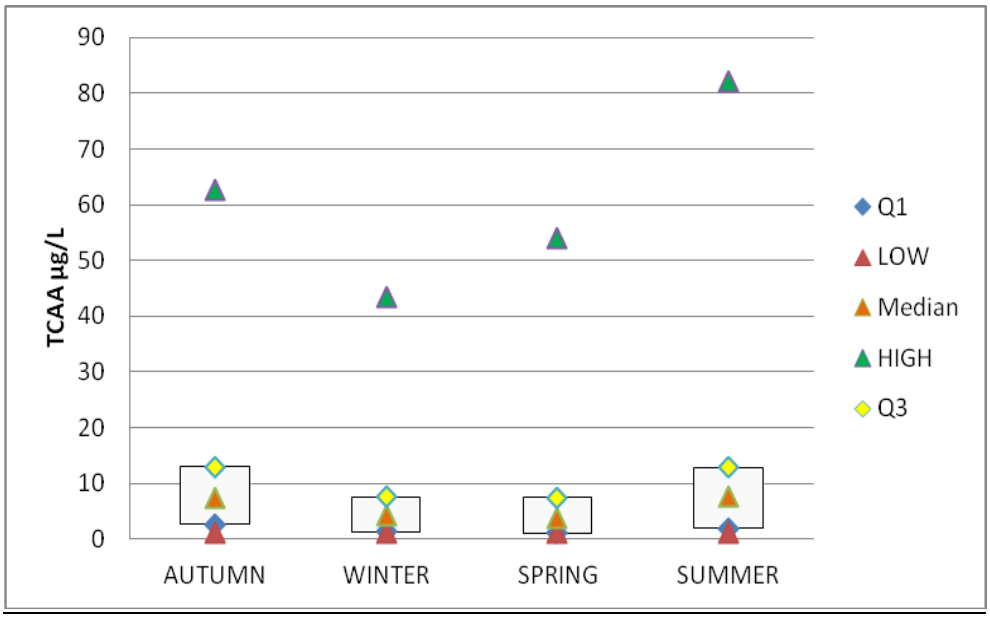


Figure 4.16 TCAA seasonal variation for all the zones

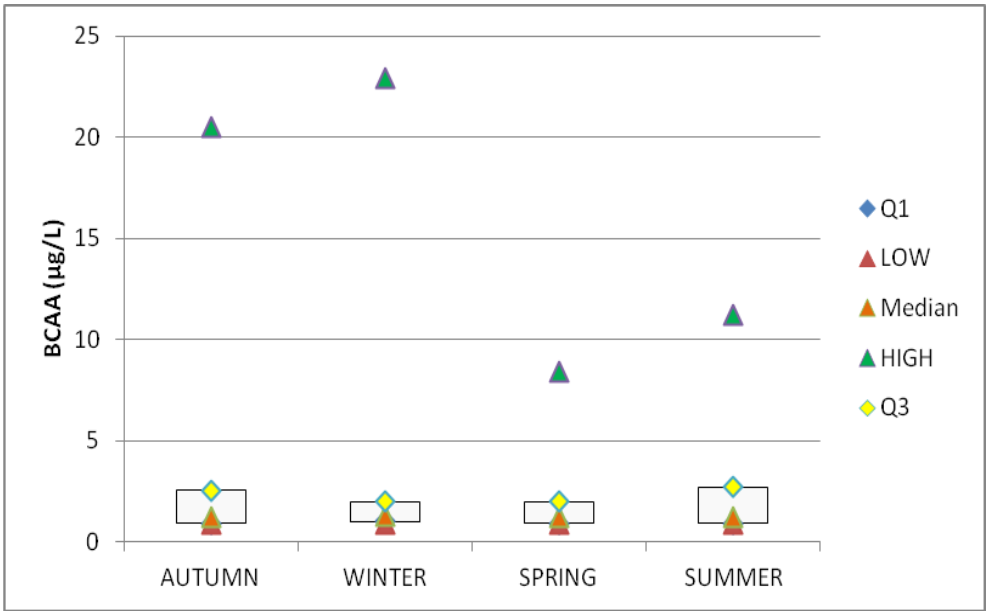


Figure 4.17 BCAA seasonal variation for all the zones

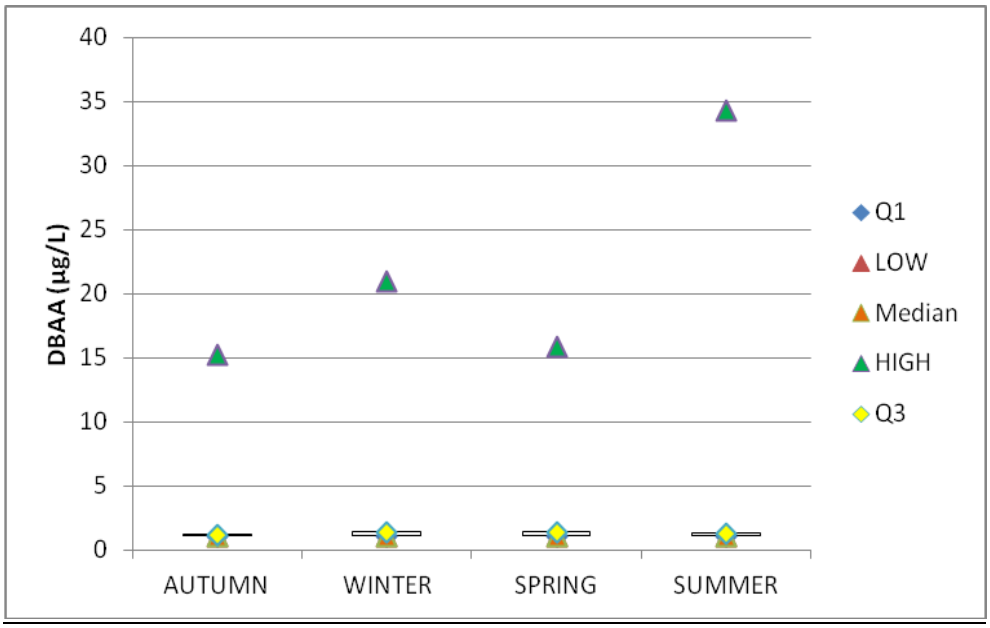


Figure 4.18 DBCA seasonal variation for all the zones

Correlation of HAAs with other parameters

Several studies looked at the correlation between HAAs and THMs, because THMs totals could be used as a surrogate for HAA levels [17]. A good correlation between THMs and HAAs can be useful because, in general, laboratory analyses for HAAs cost considerably more and are also more time consuming than the THM analyses. However this may not be appropriate as correlation between HAAs and THMs was poor in some studies [3, 9] but other studies have reported moderate to high correlations between HAAs and THMs across different water systems in various countries [20, 22, 40, 41].

In Scotland during the last few years, in order to comply with THMs regulations, water systems are converting to chloramines and/or are implementing strategies to efficiently remove NOM from the source water. So it would be interesting to see if these strategies reduced also the levels of HAAs, if THMs is used as an indicator and assume that HAAs were reduced proportionally.

In our study the results showed that there was strong positive correlation between THMs total and HAA_5 levels and a moderate to strong relationship was obtained between HAA_5 levels and TOC. Furthermore THM total showed moderate to strong correlation with TCAA and it is suggested that TCAA and THMs evolve from common precursor structures within the NOM [11, 43]. Their correlations were based on the dataset in which THMs and TOC samples were collected on the same day with HAAs samples.
The histograms showing the high degree of skeweness of each of the parameters which explains the use of the non-parametric Spearman correlation test are shown in the Appendices (Figures 7.8, 7.9, 7.10).

The scatterplots of the parameters of interest are shown (Figures 4.19, 4.20, 4.21). For example for HAA_5 and total THM we see that there is a hint of a linear pattern in the relationship of the two parameters.

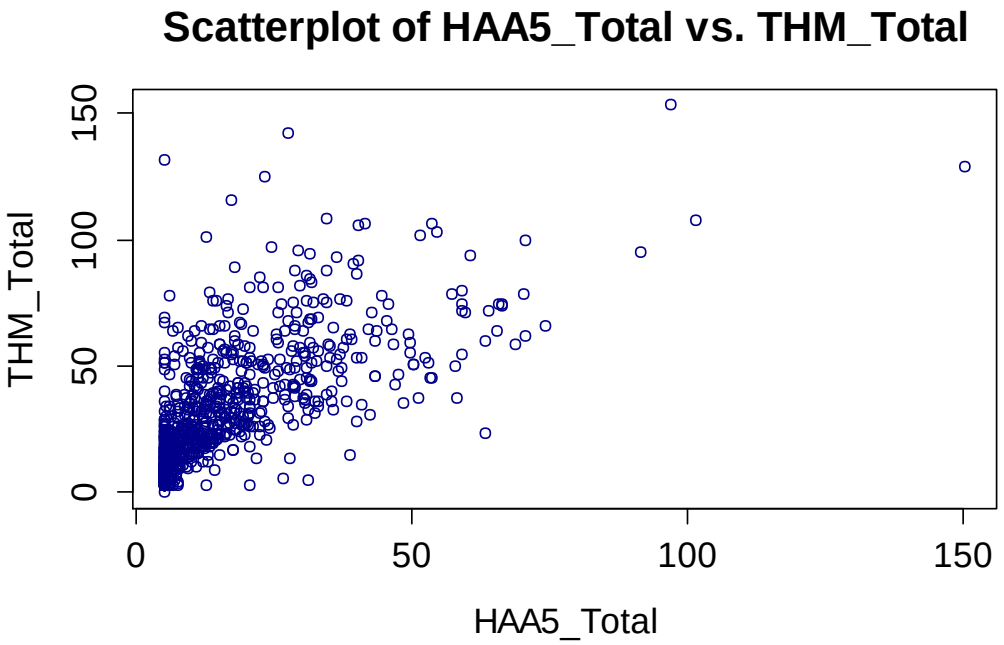


Figure 4.19 Scatterplot of the total THM levels versus the total HAA levels

For HAA_5 and TOC we see as well that there is a hint of some correlation between the two parameters.

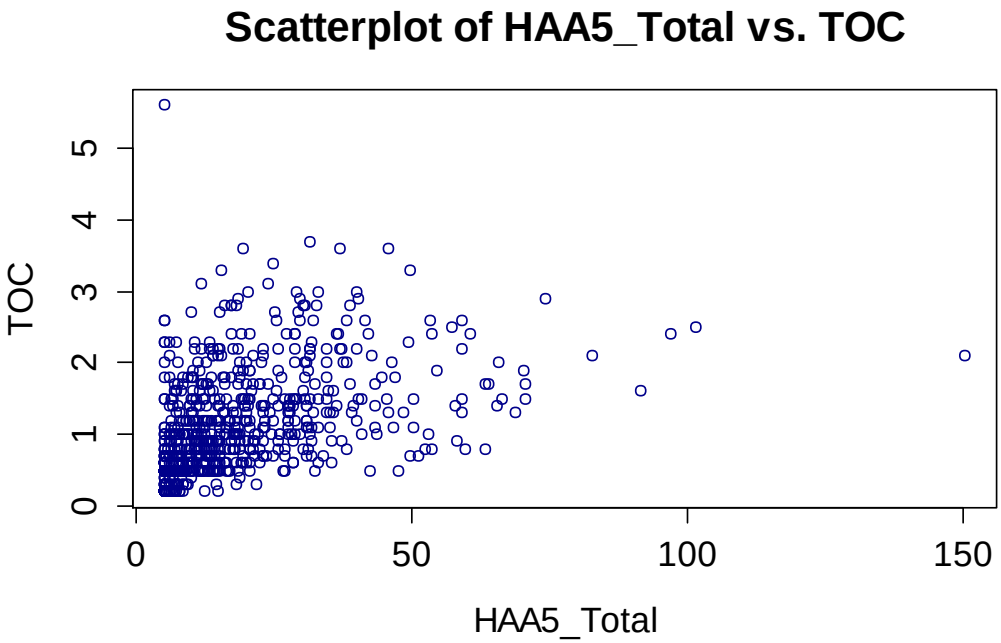


Figure 4.20 Scatterplot of the TOC levels versus the total HAA levels

Non-parametric Spearman's correlation test indicates that there is a high degree of positive sample correlation between HAA_5 and THM total (79.0%) and that correlation in general is statistically significant (p-value<0.001). In simple words, this means that the higher the increase for HAA_5, the higher the increase for Total THM and vice versa.

Non-parametric Spearman's correlation test for HAA_5-TOC indicates that there is a considerable degree of positive sample correlation between the two parameters (68.5%) and that correlation in general is statistically significant (p-value<0.001). In simple words again, this means that the higher the HAA_5, the higher the TOC and vice versa.

Below is the scatterplot of TCAA and THM total. We note again that there is a hint of some correlation between the two parameters.

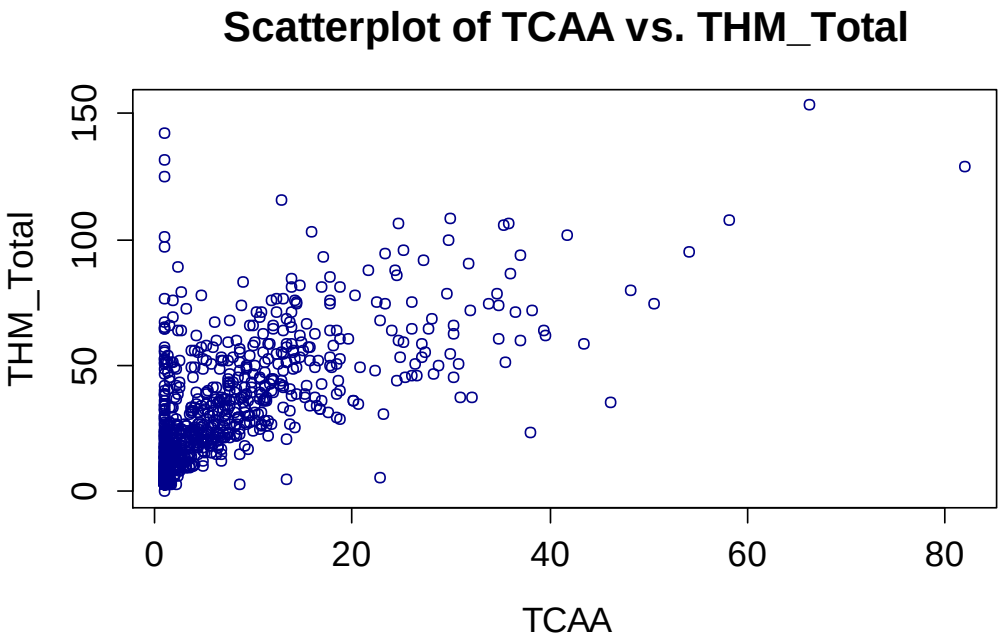


Figure 4.21 Scatterplot of the total THM levels versus the TCAA levels

Non-parametric Spearman's correlation test indicates that there is a considerable degree of positive sample correlation between the two parameters (71.5%) and that correlation in general is statistically significant (p-value<0.001).

In addition we tried to investigate the correlation of HAA_5 with different categories of TOC. The various TOC categories are defined as follows:

TOC_A: 0.2-0.5
TOC_B: 0.6-1.1
TOC_C: 1.2-2.0
TOC_D: >2.1

The descriptive measures for each category of TOC are shown (Table 4.9).

Table 4.9 Descriptive measures for each category of TOC

	TOC A (mg/L)	**TOC B (mg/L)**	**TOC C (mg/L)**	**TOC D (mg/L)**
Q1	0.4	0.7	1.3	2.3
LOW	0.2	0.6	1.2	2.2
Median	0.5	0.8	1.5	2.5
HIGH	0.5	1.1	2.0	5.6
Q3	0.5	1.0	1.7	2.8
Mean	0.44	0.83	1.52	2.6

Std	0.11	0.17	0.25	0.50

Some basic descriptive measures for HAA_5 for every category of TOC are given (Table 4.10). We observe that the mean and the median get higher as the TOC mean and median increase.

Table 4.10 Basic descriptive measures for HAA5 for every category of TOC

	HAA_5 (μg/L) A	**HAA_5 (μg/L) B**	**HAA_5 (μg/L) C**	**HAA_5 (μg/L) D**
Q1	5.3	7.95	12	16.6
LOW	5.3	5.3	5.3	5.3
Median	5.3	12.8	19.8	28.7
HIGH	47.5	63.4	91.6	150.4
Q3	6.6	20.55	30.90	37.2
Mean	7.0	16.23	23.83	29.66
Std	4.56	11.34	15.98	18.79

The median HAA_5 value for each of the four categories of TOC is shown (Figure 4.22) and a linear trend is observed.

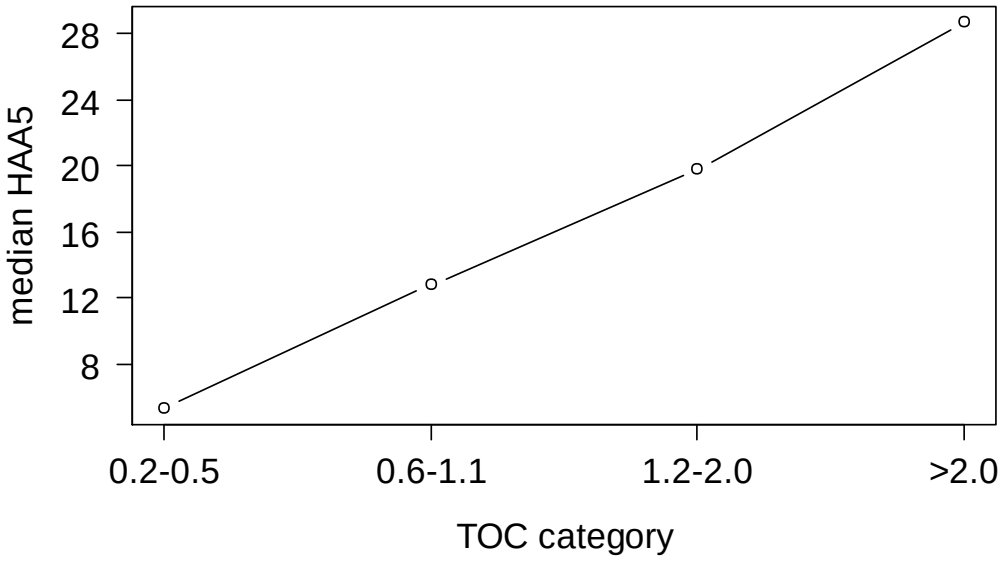


Figure 4.22 Median HAA5 value (μg/L) for each of the four categories of TOC (mg/L).

However, as we can observe about the correlation of HAA_5 within each category of TOC, all in all, none of the Spearman's correlation coefficients below is large enough to be taken into consideration. Therefore, there seems to be negligible or very mild correlation of HAA_5 within each category of TOC.

(r_s)HAA_5_A and TOC_A = -0.05
p-value = 0.3193

(r_s)HAA_5_B and TOC_B = 0.22
p-value = 0.000265

(r_s)HAA_5_C and TOC_C = 0.07
p-value = 0.3117

(r_s)HAA_5_D and TOC_D = 0.11
p-value = 0.3526

In short when the results are considered as a whole there is generally strong correlation between HAA_5, and THMs, between TCAA and THM total and between HAA_5 and TOC for all the distribution zones. Therefore the regulated THMs could be good indicators of the presence of HAAs observed in the drinking water systems under study however that needs to be further investigated.
Furthermore we can assume that HAAs were reduced proportionally with THMs when THMs reducing strategies were implemented at the WTWs, however having samples of final water before the distribution system would be better in order to be certain.
Correlation between THMs and HAAs may differ between various water distribution zones. If we consider a specific distribution system, we cannot be 100% certain that these two parameters will correlate, due to the different behaviour of HAAs and THMs along a distribution system according to the location and the season. Thus correlation should be determined between these parameters for a specific distribution system [34]. Rodriguez et al. (2007) in a study carried out in Quebec, Canada found out that correlation between HAA total and THM total in a specific distribution system may be better in cold water in locations with low residence time, compared to warm water [34]. Their correlation is heavily dependent on water temperature and residence time [20, 22].
Similarly as with the seasonal variations of HAAs, the correlations between THMs and HAAs found in a specific distribution cannot be used for other distribution systems, because they depend, as mentioned above, not only on the water temperature and residence time but also on the type of water source, the disinfection strategy used and the water treatment applied at the WTW [6]. There are too many variables that are important in the formation of THMs and the formation and degradation of HAAs.
Furthermore TOC can be considered as an indicator of the levels of NOM and therefore HAA precursors present in water. A higher TOC levels is likely to produce more HAAs.

4.2 Fate of HAA in a distribution system: HAA behaviour and distribution factors such as chlorine residual, bacterial levels and mains material.

The data below show the levels of HAAs and THMs measured in the distribution samples collected in July 2014 and the raw data are presented in Table 7.10 in Appendices. Free and total chlorine, TOC, pH, and bacterial levels using flow cytometery were measured as well for the distribution samples and these data are also found in the Appendices.

The spatial variation of THMs levels in distribution systems is well recognised. THMs were observed to increase in the distribution system and become stable in the distribution system extremities. This is due to the combination of the continuous chemical reaction between NOM and chlorine forming THMs, along with the hydrolysis reactions of intermediate DBPs which break down in order to form THMs [2]. However HAAs behaviour in the distribution system is different. Many full-scale studies showed that HAAs levels may decrease, increase and may not change with increasing residence time in distribution systems [13, 52, 49]. Especially in the UK a study carried out by Parsons and Goslan, (2011) has shown both a reduction and an increase of HAAs in distribution.

Similarly in our study HAA5 were observed to both decrease and increase within both distribution systems but here their behaviour in each distribution system is investigated in detail. Two systems were investigated: one chloraminated (Pateshill) and one chlorinated (Rosebery).

4.2.1 Fate of HAAs in Pateshill distribution zone

As mentioned in the literature review HAAs formation and HAAs degradation are the major processes that could change their concentration in a distribution system [31]. Several parameters such as chlorine residual, pipe material, bacterial counts, natural organic matter (NOM), pH, and temperature are important factors affecting the fate of DBPs and HAAs within the distribution system [1,3,9,11].

Observing the HAA_5 behaviour along the distribution system of Pateshill, HAA_5 were lower at the last sampling point than at the first by 46.3%. This was associated with a decrease in chlorine residual. There are many factors that influence the residual chlorine decay in a distribution system; such as pH, water temperature, initial chlorine concentration, pipe diameter and materials, corrosion and biofilm present on the pipe wall, nature and quantity of organic matter present in water, hydraulic conditions [60]. As the distributed water is chloraminated the levels of free chlorine were expected to be very low. It has been observed that monochloramine is more likely to be stable and effectual at inactivating bacteria and controlling regrowth than free chlorine [35].

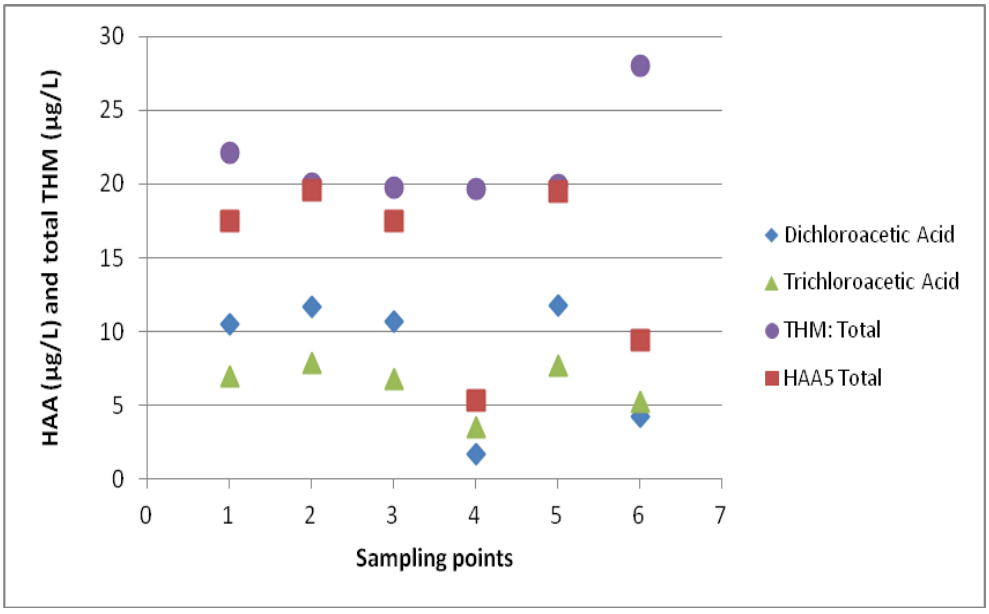


Figure 4.23 Spatial variability of THM total and HAAs species along the distribution system of Pateshill.

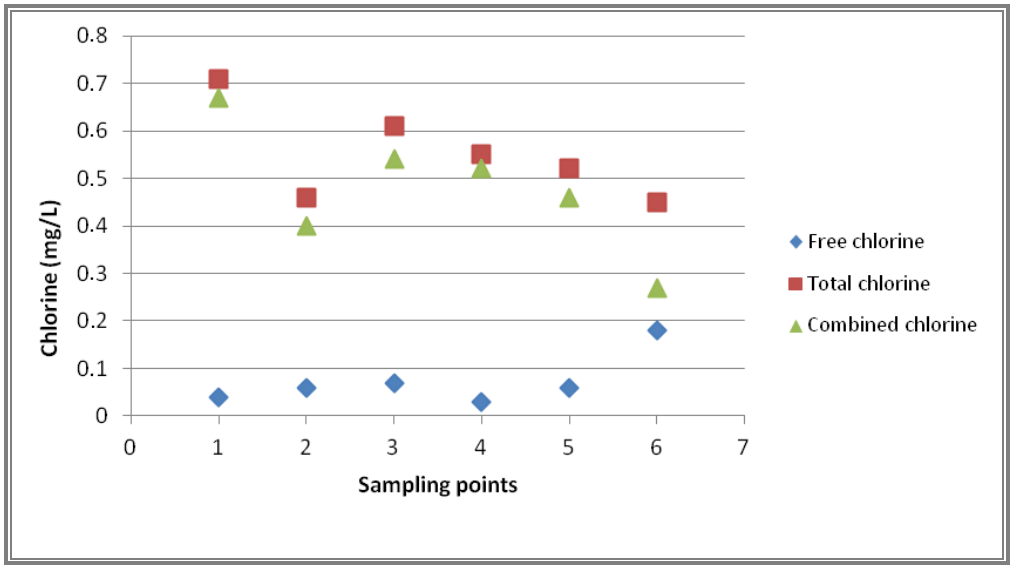


Figure 4.24 Spatial variability Chlorine residual along the distribution system of Pateshill.

HAA_5 show a substantial drop on the middle of the distribution system (69.7%), and then they increase again substantially to fall again at the end (51.8%). The first fall in HAA_5 is principally arising from the decrease in TCAA and DCAA. The increase in HAA levels correspond to the increased contact time between the free chlorine residual and HAA precursors. In our sampling period that is during summer, the rate of formation of HAA increases with an increase in the water temperature. However increasing temperature accelerates the chemical and biological degradation rates of some HAA species [17, 42]. As we know the HAAs are not as chemically or biologically stable as THMs in aquatic systems. Their concentration in the

distribution system could be increased in the presence of residual chlorine and organic compounds or due to the decomposition from other DBPs and be decreased by biodegradation or hydrolysis and abiotic degradation [11, 48].
The dihalogenated acetic acids are preferentially formed during chloramination so the average DCAA concentration (8.4μg/L) is higher along the distribution system compared to the average TCAA concentration (6.4 μg/L). As we can see in Figure 4.23 in the first sampling points the rate of formation of TCAA and DCAA is similar, however later the rate of formation but also of degradation of DCAA is greater compared to TCAA.
The ratio TCAA:DCAA was stable from the first to the third sampling location but on the fourth location their ratio increased to 2 and on the last sampling point was 1.2.

Several studies have shown the involvement of microorganisms in the degradation of HAAs in low levels of disinfectant residual [11, 48].
In our case where chlorine residual is very low and the sampling month was July.So there are quite favourable conditions (low residual chlorine, warm water) for the biodegradation of HAAs.Thus biodegradation can be one explaination for the decrease of HAAs observed on sampling point 4 and 6. Zhang et al. found that trihalogenated HAA species are more stable than mono and dihalogenated species [15].In our case DCAA decreased substantially but TCAA decreased at a slower rate.

Furthermore the other HAAs compounds levels didn't change within the distribution system and their concentrations were under their detection limits.
Concerning the TOC concentrations, its value didn't vary significantly in the distribution system and its concentration ranged from 1.3 to 1.9 reaching the lowest value at the last sampling point. The pH didn't vary significantly along the distribution system and its value ranged between 7.7 and 8.4.

If we observe the results of the flow cytometry we note a decline in the levels of both total and intact cells. On the sampling point 4 and 6 we observe a significant rise of intact levels reinforcing our hypothesis of HAAs biodegradation. However the substantial increase of intact cell levels on the second sampling point, probably associated with the decrease of total chlorine didn't cause any HAA biodegradation. However the factors that affect HAAs biodegradation in the distribution system are not clearly understood. Although bacteria could be viable, they might not be metabolically active regarding HAA biodegradation [31]. Lack of degradation can be observed if there is lack of HAA degrading organisms, or due to environmental factors like pH, temperature, micronutrient limitation, dissolved oxygen limitation, or big pipe diameter [55].
Furthermore in that part of the distribution system the iron proportion is 61%, much less compared to the other parts of the distribution system. That may play a role on the formation of the biofilms on the pipe surface. As we know growth of bacteria on surfaces to form biofilms is possible on any type of surface. Although it might be more favourable on corroded iron.
One very important note is the large number of dead cells found from the flow cytometry results. Thus large numbers of dead cells can contribute to HAA formation.
Free chlorine (HOCl) is a powerful oxidant that can react with organic compounds like the dead cells and create more DBPs and HAAs. In addition to free chlorine, combined chlorine (chloramines) reacts with organic matter to form DBPs, but at a much slower rate [2].

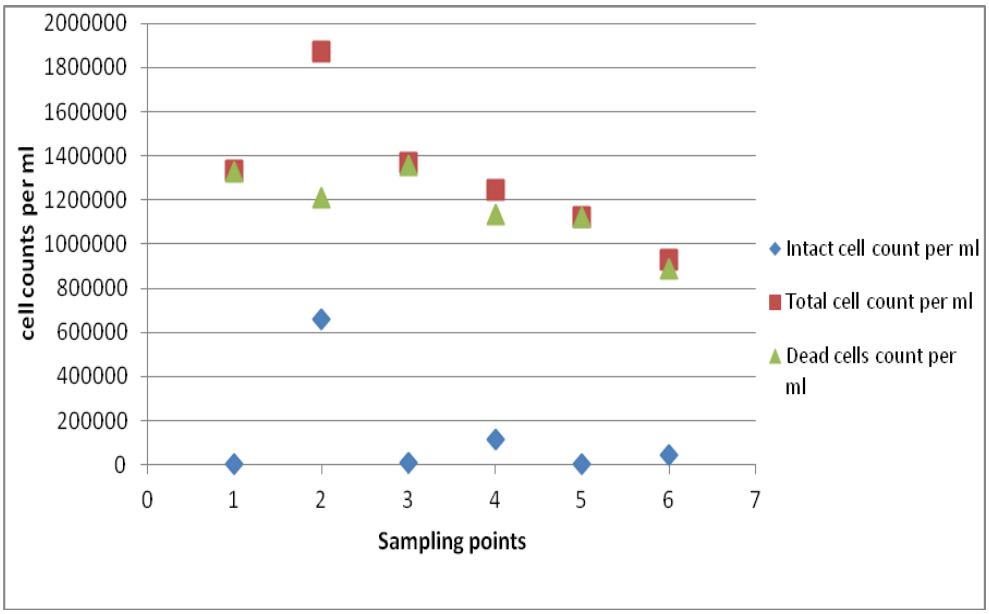


Figure 4.25 Spatial variability cells counts along the distribution system of Pateshill.

THMs were stable and increased at the last sampling point. Again the increase in THMs levels corresponded to the increased contact time between the free chlorine residual and combined chlorine and DBPs precursors. Between the fifth and the last sampling point we observe an increase in free residual chlorine as well. Many studies have reported similar results about the increase of THMs concentrations along the distribution system. But also this increase maybe due to the decomposition of trihalogenated acetic acids to form their corresponding THMs [51, 52].
However as we saw before TCAA degraded in the fourth and last sampling point and THMs increased only on the last sampling point.One explanation may be that the rate of THMs formation is slower than HAAs formation [32]. A large portion of the distribution pipes are composed of iron but in our results we didn't find any evidence of dehalogenation. Moreover most iron water pipes have been in place for decades and are corroded so absorption to iron minerals is a potential loss pathway for HAAs.

4.2.2 Fate of HAA in Roseberry distribution zone

The THM total levels in Rosebery distribution zone slightly increased along the distribution piplines (5.5 % from the first to the last sampling point). They decreased from the first to the second sampling point (28.9%) from which they increased to reach almost the ultimate concentration of 48.2 μg/L.
This increase is due to the continuous contact of both precursors and residual chlorine present. But also this increase may also be due to the decomposition of trihalogenated acetic acids to form their corresponding THMs [51, 52]
As we know THMs tend to be stable in water distribution systems and this drop of 28.9% between the first and the second sampling point cannot be explained. An explanation may be the different flow rates of the water. The first sampling was done

during the minimum consumption time, at 4:15 pm and all the other sampling was carried out between 11am and 2 pm (consumption peak) [62].
Observing the behaviour of HAA_5 in Rosebery's distribution system we note that HAA_5 concentrations decreased from the first to second sampling point (44.2%) and from the third to the fourth (37.8%).Their concentrations almost double from the second to the third point and slightly increased from the fourth to the last sampling point. Though generally a decrease of HAA_5 concentration was observed at 24.6 % from the first to the last sampling point.

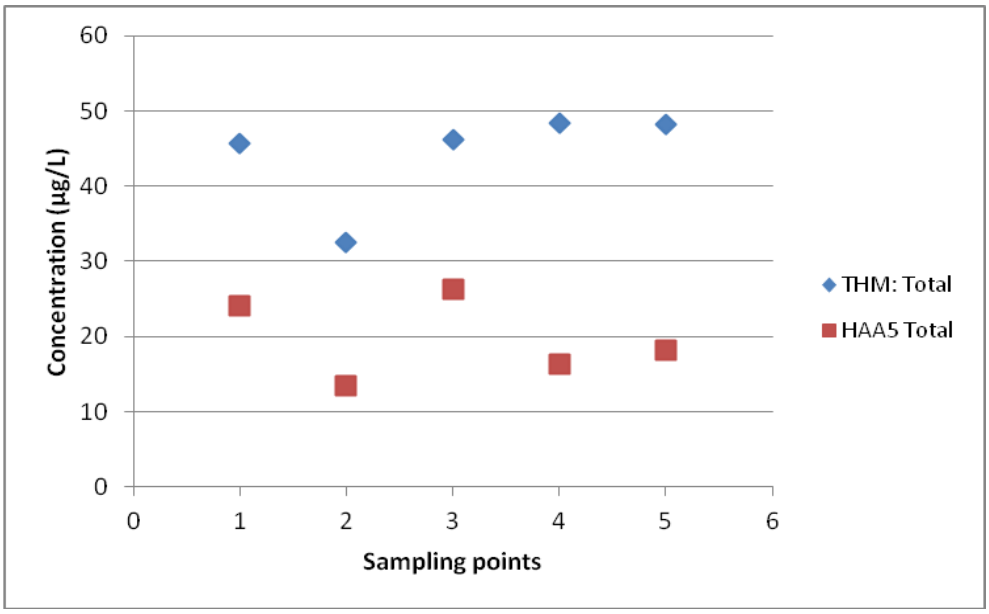


Figure 4.26 Spatial variability HAA5 and THM total along the distribution system of Rosebery.

The desired levels of free and total chlorine must be between 0.4-0.8 mg/L however very low levels of free chlorine were detected. These low chlorine residual levels are due to potential ingress of rainwater in the clean water tank. Also low flow velocity in the pipe may lead to low chlorine residual, but probably this is not the case because during summer the water demand is higher.
In our case where chlorine residual is very low, beginning at 0.18mg/L free chlorine to reach 0.03 mg/L at the last sampling point.

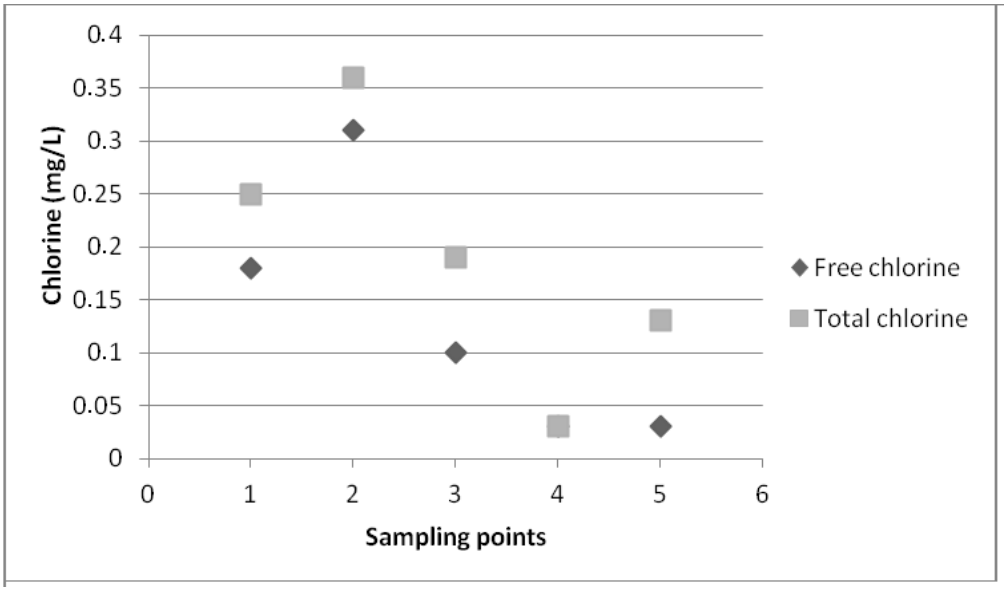


Figure 4.27 Spatial variability Total and Free chlorine along the distribution system of Rosebery.

So there are quite favourable conditions (low residual chlorine, warm water) for the biodegradation of HAAs. Another evidence of biodegradation is the degradation of DCAA.

The dominant HAAs species were TCAA and DCAA with average concentrations 12.5 μg/L and 6.9 μg/L respectively. The first fall in HAA_5 is principally arising from the decrease in DCAA and TCAA. Both of them decreased to almost the same degree 42.9% and 45% respectively. However on the second drop of HAA_5 TCAA was stable and slightly increased on the last sampling point of the distribution system, but DCAA decreased 70 % from the third to the forth sampling point.
Generally along the total sampling points TCAA decreased 4.7 % and DCAA 57.1%.

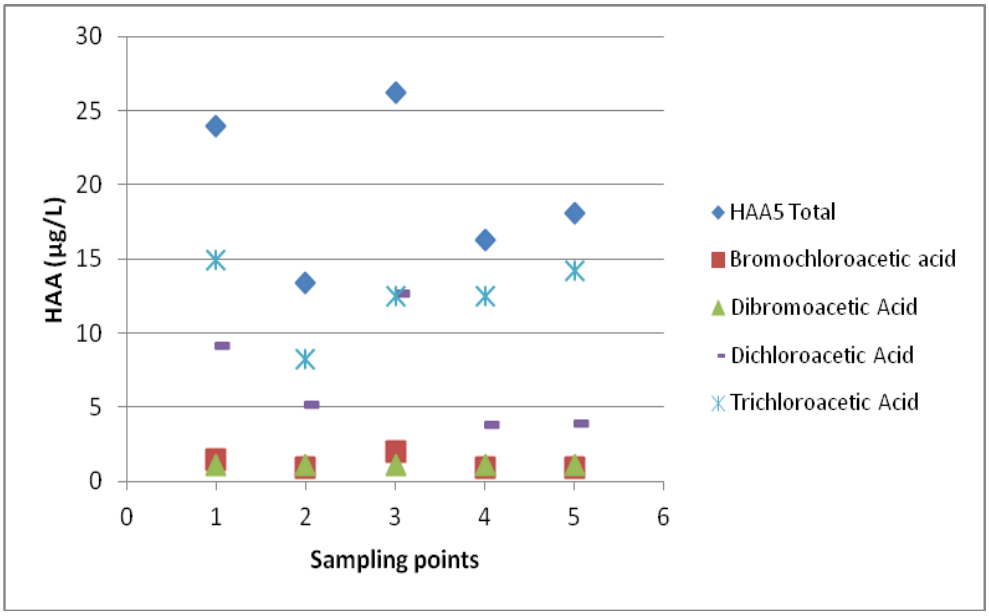


Figure 4.28 Spatial variability HAAs speceies along the distribution system of Rosebery.

Furthermore BCAA is the only other HAAs species whose concentration varied along the distribution system and its behaviour was similar to that of DCAA. It is known that dihalogenated HAAs are likely that are formed through similar chemical pathways and that is maybe the reason they have similar behaviour [11, 24].
All the other compounds were found at concentrations lower than their detection limits.

As we mentioned before chlorine residual, bacterial counts, pipe material, natural organic matter (NOM), pH, and temperature are important factors affecting the fate of HAAs. Thus one possible explanation of the drops of both HAA_5 and TCAA and DCAA is the relatively low levels of NOM (see levels of TOC) and chlorine residual. Furthermore the levels of dead cells as we can see on the next figure is quite low compared to the number of dead cells detected in the chloraminated zone of Pateshill.
It should be noted that most iron water pipes have been in place for decades and are corroded so absorption to iron minerals is a potential loss pathway for HAAs [14, 54].

Moreover when the HAAs decreased, higher levels of pH were detected at the sampling points, reaching the value of 9.1 on the second and 9.4 on the forth sampling point. As we know among the HAA species, the formation of trihalogenated acetic acid species tends to decrease with increasing pH whereas dihalogenated and monohalogenated acetic acid species are relatively independent of pH [11]. Thus in our case the rates of formation of TCAA may decrease at elevated pH. Furthermore THMs tends to increase with increasing pH. Thus water distributed with free chlorine at pH values greater than 8 will have lower HAA to THM ratios than water distributed at lower pH values [11].That is the case in this study.
TCAA is observed to decrease slightly more than dihalogenated acids on the second sampling point. One explanation can be the increasing pH, so less TCAA are formed. Another explaination is that trihalogenated acetic acids (TCAA) can decompose to form their corresponding THMs [51, 52]. However there is no increase of THMs in that part of the distribution system.

Moreover abiotic reduction of HAAs is possible in the iron pipes. The water travels through a pipeline consisting of 92% iron to reach a pipeline concisting of 63% iron on the second sampling point. The studies of Hozalski et al. (2001) and Zhang et al. (2004) have shown that dehalogenation occurs in the presence of iron distribution pipes with TCAA degrading to DCAA. This may have occurred here as the TCAA:DCAA ratio and TXAA:DXAA (as BCAA was observed as well) was observed to decrease through the first to the third points of the distribution.

On the second point of HAAs decreasing the most probable reason is biodegradation. In this case TCAA stays stable and DCAA and BCAA decreased substantially.

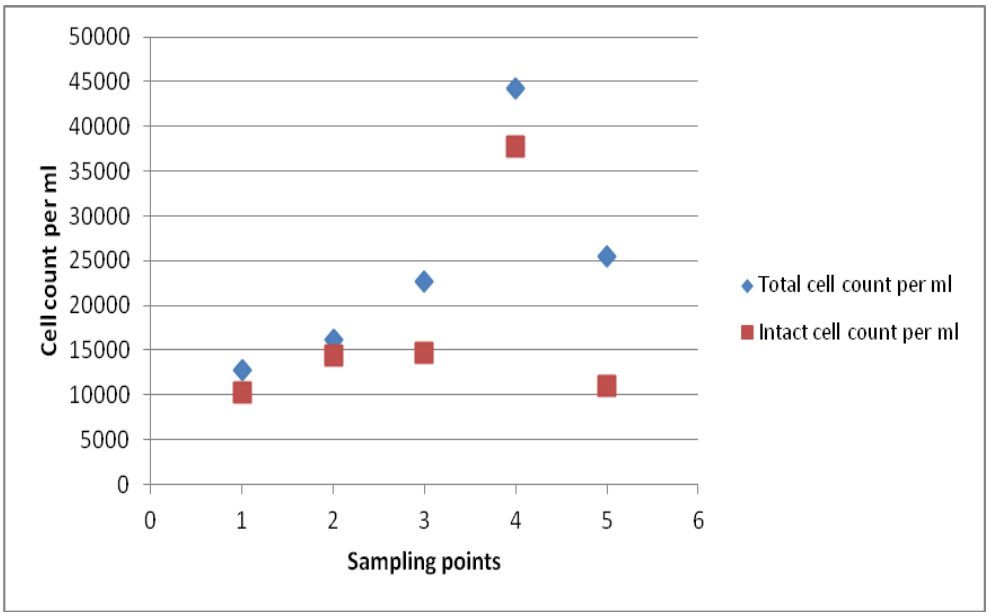


Figure 4.29 Spatial variability of total cell and inact cells along the distribution system of Rosebery.

The chlorinated water of Rosebery distribution zone behaves as expected. THMs stay stable after an initial increase when chlorine residual is minimal. However HAAs increase and decrease along the distribution system as they are not biologically and chemically stable. There is evidence that biodegradation occur and abiotic reduction of HAAs is possible in the iron pipes.
During July the increasing temperature accelerates the chemical and biological degradation rates of some HAA species and the formation reaction of DBPs [17, 42].
Residual chlorine reacts with various substances in the water that can be DBPs precursors and on the pipe walls resulting in increases in THMs and HAAs concentrations [17].

In Pateshill distribution zone THMs had similar behavior; they stayed stable and increased at the end of the distribution system. However as Pateshill is a chloraminated zone the levels of THMs and TCAA are lower compared to the chlorinated Rosebery zone. And the levels of DCAA are higher compared to the levels of Rosebery zone.
In the chloraminated zone as well HAAs increase and decrease along the distribution.It is important to note the large number of dead cells found from the flow

cytometry results in Pateshill distribution zone and generally the higher levels of total and intact cells. Thus large numbers of dead cells can contribute to HAAs formation.

Unfortunately the selected sampling points are not uniformly distributed along the distribution system to represent the entire range of residence times (short, medium and long flow residence time). Thus we could have more opportunity for degradation at the end of the distribution sytems.

However low chlorine residual were measured probably because of some distribution system deficiencies or because during summer months when higher temperatures occur, chlorine consumption by the pipes and reaction with substances in the bulk water such as NOM is promoted [16] .There is a possibility of booster chlorination (re-chlorination) having been applied between the first and the second sampling points in the Rosebery distribution zone. In the Pateshil distribution system there was no booster chlorination. That could explain the slight increase of chlorine residual concentrations in that system.

4.3 Limitations and Recommendations

This study was a preliminary study to evaluate the levels of HAAs in the different distribution zones of Scotland and find out which zones experienced higher concentrations of HAAs in order to continue trying to lower their levels in the distributed drinking water. However some limitations have arisen from this study.
Firstly relatively few samples were collected per zone throughout the year and further work needs to be conducted to confirm these results. For each distribution zone the sampling points were random sampling points and as we saw HAAs degradation occurs along the distribution system. Therefore in many of our zones we found out that there were big variations in HAAs values throughout the year or intra seasonal variations, but it is not known if that variation is because of the seasonal variations or/and because the sampling points are different and degradation (chemical or biological) occurred.
Secondly the use of HAA_5 is a limitation of our study because we are not able to examine the HAA_9 mixture and the proportion of brominated HAAs species. Furthermore HAA_9 levels can be 20-50% higher than HAA_5 levels in high bromide concentration of the chlorinated water.
Thirdly the sampling points of the spatial variability study of the two zones were selected based on distances from the WTW and accurate water residence times are not known. Neither hydraulic conditions nor characteristics (pipe connections, water flow path, presence of reservoirs and chlorination boosters) [6] of the network were considered when sampling points were identified and a point may be affected by water coming from a reservoir or another network.

The ideal would be that the water travelling at these sites must come exclusively from Rosebery WTW and Pateshill WTW respectively and must not have been rechlorinated within the network. The selected sampling points should represent the entire range of residence times: short, medium and long in the distribution system. If the concentrations of HAA in the distributed water are not much higher from the HAAs concentrations from the treated water leaving the WTW, more efforts should be made to reduce the levels of HAAs formed at the WTW rather than in the distribution system.

In addition to distributed water samples, samples from the raw water of the distribution zones would be very useful in order to evaluate the levels of DBPs precursors. Raw water characteristics like the type and concentration of NOM and the concentration of bromide can give us information about the level of potential HAAs formed. Thus information on HAAs precursors in these WTWs would help to explain some of the trends that were detected.
Moreover a more robust full scale sampling program in several locations of distributions zones of concern that experienced the highest HAAs concentrations, would allow a more detailed picture of the spatio-temporal variations of HAAs throughout a distribution system. Temporal-spatial variability data of these zones could be used to identify locations with higher human exposure. Thus these results could help to determine the timing, the location and at what frequency samples should be taken in a distribution system in order to estimate the representative exposure of population served by a distribution system. And this is particularly essential due to the effect of short term exposure to HAAs on reproductive outcomes.
The data of that study maybe useful for epidemiological, public health studies, water regulatory agencies, or others who are interested in the fate of DBPs in water systems.

Our research demonstrates that bacteria biodegrading HAAs exist within these drinking water distribution systems, but a better understanding of the biodegrability of HAAs in drinking water systems is needed.
It would be very interesting to characterise the biodiversity found and identify the bacteria responsible for HAAs degradation in the distribution systems of Scotland in order to better understand HAAs degradation and fate in these distribution systems.

Moreover studies defining the specific organics responsible for the HAAs formation in UK drinking water will be very useful for the WTWs in order to understand the sources of HAA precursors and to identify management actions that can reduce their occurrence, if regulation occurs in the UK.
Nevertheless our study shows that the pipe surface is a crucial factor affecting HAA fate in a distribution system but further work is needed to confirm that. Unfortunately currently only limited amount of reports are examining the effect of pipe materials on the formation and fate of DBPs and HAAs and more studies need to be allocated for that topic.

Water treatment works should continue trying to reduce their DBPs levels in public drinking water, while ensuring that disinfection is never compromised and achieve an effective control against waterborne microbiological diseases. Aside from THMs and HAAs other ‘‘emerging’’ DBPs exist, some of them less studied up to now, but with higher potential toxicity and these sould be considered in future studies particularly where chloramination is employed to suppress formation of DBPs.

Chapter 5. Conclusions

5. Conclusions

This study provides an interesting picture of HAAs levels in distribution water in Scotland and very useful data for Scottish Water to estimate the implications of possible future legislation for HAAs in drinking water. A statistical analysis has been carried out using measurements of HAAs concentrations and other water quality parameters from 298 Scottish water distribution zones. This study also allowed evaluation of the impact of seasons on HAAs concentrations and speciation in Scotland's distribution zones. The spatial variability of HAAs concentrations in two distribution zones using different disinfection strategies was also studied and the impact of the two most common disinfection strategies on HAAs formation and fate along the distribution system was investigated.

- The median concentration of HAA_5 was 11.45μg/L and was similar to previous studies. The average HAA_5 in distribution systems were about 50% lower than total THMs. Comparing the concentrations of HAA_5 among the different regions of Scotland, the differences are not that pronounced.

- Generally chlorinated HAAs dominated in the waters of the distribution under study. The dominant species were TCAA and DCAA, where the sum of these two species represented over 83.1% of the total HAA_5 (41.2 % and 41.9 % respectively). The bromine-containing DBPs were found in very low concentrations compared to the other HAAs species. The bromide concentrations present in the distributed water were relatively low (75% of the values are less than 0.047mg/l).

- If Scotland had a similar limit to the US (60μg/L), 93.3% of zones would comply with the regulated limits. The systems out of compliance were supplied by small WTWs (e.g., less than 3,300 people) therefore the small water treatment works would need to focus on HAAs control efforts. The very small WTWs (<500 people) have the lowest concentration of HAA_5, on a median basis due to their use of ground water sources and/or membrane filtration. The highest median concentration of HAA_5 appears in networks of 500-3300 people, where there is also the widest range of concentrations.

- Similar trend were found for the total THMs with only one zone experiencing higher average concentrations than the regulatory limits (100μg/L). That zone is supplied by a bigger WTW serving 10001-100000 people but the limit was only exceeded on one occasion.

- The low concentrations of HAAs in bigger WTWs are due to the fact that most systems in large cities tend to implement more effective DBP control strategies and the NOM has been efficiently removed. The higher levels found are thought to be due to the non-optimized removal of organics at these works and maybe due to the very high NOM load in the raw water especially with high aromaticity (good HAAs precursors) or due to the disinfection strategy used. However our data do not allow us to make conclusions about why some WTWs experienced higher HAAs concentrations in their distribution system

and specific investigation into the corresponding water treatment and distribution zone is needed.

- The total HAA_5 levels in water distribution zones vary considerably according to their water source and the disinfection strategy used. Most of the zones used surface water and only 13% of the 298 zones used ground water during the study period. The principal type of disinfectant used in most zones was chlorination and only 14% of zones are supplied by chloraminated water. Low HAA_5 levels (the median was lower than 5.3 μg/L that is the detection limit of the analysis method) were observed in the groundwater systems and higher were observed in the surface water systems (the median was 12.35 μg/L). The lower TOC concentrations in ground waters compared to surface waters indicate that as well. TCAA and DCAA were the dominant HAA species in both ground water and surface water supplied zones. We detected somewhat lower concentrations of HAAs and THMs after chloramination compared to chlorination and TCAA was reduced by chloramination. DCAA and TCAA were almost in equal levels in chlorinated waters but DCAA was the dominant group detected when using chloramination. The USEPA regulatory limit was not exceeded in chloraminated zones.

- When the data sets from all distribution zones were combined there was a strong correlation between total THMs-HAA_5, total THMs-TCAA and HAA_5-TOC. Overall, TOC can be considered as an indicator of the levels of NOM and therefore HAAs precursors present in water. A higher TOC levels is likely to produce HAAs. Furthermore the regulated THMs could be good statistical indicators of the presence of HAAs. However correlation between THMs and HAAs may differ between various water distribution zones. If we consider a specific distribution system, we cannot be 100% certain that these two parameters will correlate, due to the different behavior of HAAs and THMs along a distribution system according to the location and the season.

- Seasonal variations of the concentrations of different HAAs species were observed. The highest median and the widest range of HAA_5 concentrations were observed in autumn and summer (13.2 and 14.5 respectively) while the lowest were obtained in winter and spring season (10.4 and 9.7 respectively).The seasonal pattern of HAA_5 formation was similar to that for total THMs, with a seasonal variation more pronounced in comparison to HAAs.

- The seasonality in water distribution zones as well, vary considerably according to their water source and the disinfection strategy used. No seasonal variation in HAA_5 were observed for the ground water supplied zones compared to surface water supplied zones and the seasonal variation for the chlorinated zones is more pronounced compared to chloraminated zones. There is a higher increase of HAA_5 during summer in the chlorinated zones

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- In addition the behavior of DCAA and TCAA are not the same during seasons. The median data show almost no seasonal variation for the DCAA however the seasonal variation of TCAA is more pronounced and higher concentrations were detected during summer and autumn. That is another evidence of

degradation of DCAA in warm waters due to the presence of biofilm into the distribution system. Another explanation could be that there is a shift not only in the quantity but also in the composition of NOM during the year, and as we know DCAA and TCAA have different precursors.

- Spatial variations of the concentrations of HAA_5 and the different HAAs species and THMs were observed along two distribution systems. The pattern of evolution in our study is different for the two DBPs as expected from the literature. THMs generally presented stable and increasing concentration profiles along the system, whereas HAAs increased and decreased towards the end of the sampling location, a phenomenon probably related to microbiological degradation of these substances. This variation was also true for the system supplied by chloraminated water. There is also evidence that abiotic reduction of HAAs is possible in the iron pipes for the chlorinated distribution system.

- It is important to note the large number of dead cells found from the flow cytometry results in the chloraminated distribution zone and generally the higher levels of total and intact cells. Thus large numbers of dead cells can maybe contribute to HAAs formation.

- Our research demonstrates that bacteria biodegrading HAAs exist within these drinking water distribution systems, but a better understanding of the biodegrability of HAAs in drinking water systems is needed. Moreover our study contribute to the state that the pipe surface is a crucial factor affecting HAA fate in a distribution system but further work is needed to confirm that.

- The spatial and seasonal variation profiles of HAAs concentrations observed in the distribution systems of Scotland during this study showed that the exposure of the public to HAAs may vary spatio-seasonally along a given distribution system.

All the above show that the formation of HAAs, their speciation and their fate in a distribution system is a complex phenomenon and depends on several factors including season, characteristics of water, treatment procedures, water distribution pipe materials. Distribution systems are dynamic in nature and there may be significant temporal and special variations in DBPs concentrations. Given the complex nature of the distribution systems and the number of the factors that affect the formation and fate of HAAs and their interactions along a distribution system, it is important that the DBP precursors are reduced as much as possible at the treatment works.

Chapter 6. References

6. References

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Chapter 7. Appendices

7. APPENDIX A: Supporting information for Chapter 3.

Table 7.1 Zone programme sampling frequency

Name	Description	Sampling Frequency
Acharacle	Distribution for Zone Acharacle (Acharacle East of Ardnamurchan)	6
Achiltibuie	Distribution for Zone Achiltibuie (Achiltibuie, Wester Ross)	6
Afton	Distribution for Zone Afton (Galston, Cumnock, New Cumnock)	6
Alexandria	Distribution for Zone Alexandria (Alexandria, Cardross, Balloch, Bonhill)	6
Amlaird	Distribution for Zone Amlaird (North Kilmarnock, Galston, Greenholm)	6
Applecross	Distribution for Zone Applecross (Applecross west of Lochcarron)	6
Ardfern	Distribution for Zone Ardfern (Ardfern north end of Sound of Jura)	6
Ardrishaig	Distribution for Zone Ardrishaig (Lochgilphead, Ardrishaig,Port Ann and Cairnbaan)	6
Ascog Bute	Distribution for Zone Ascog Bute (central Rothesay, east Bute)	6
Assynt	Distribution for Zone Assynt (Dingwall, Alness, Black Isle)	6
Auchneel	Distribution for Zone Auchneel (North Stranraer)	6
Aultbea	Distribution for Zone Aultbea (North east of Loch Ewe Wester Ross)	6
Backies	Distribution for Zone Backies (Golspie, Brora Sutherland)	6
Badachro	Distribution for Zone Badachro (South shore Loch Gairloch Wester Ross)	6
Badcaul	Distribution for Zone Badcaul (Badcaul Little Loch Broom Wester Ross)	6
Badentinan	Distribution for Zone Badentinan (Elgin Dufftown Rothes)	6
Ballater	Distribution for Zone Ballater (Ballater, Tarland West Aberdeenshire)	6
Ballygrant Islay	Distribution for Zone Ballygrant Islay (Port Askaig and Ballygrant Islay)	6
Balmichael Arran	Distribution for Zone Balmichael Arran (Brodick, Lamlash, Whiting Bay, Blackwaterfoot)	6

Balmore A	Distribution for Zone Balmore A (Muirhead, Moodiesburn, Stepps, Caldercruix, Greengairs)	6
Balmore B	Distribution for Zone Balmore B (North Airdrie, Coatbridge, Baillieston, Garrowhill)	6
Balmore Carron Valley	Distribution for Zone Balmore Carron Valley	6
Balmore C5 North	Distribution for Zone Balmore C5 North (Bishopbriggs, Springburn, Cadder)	6
Balmore C5 South	Distribution for Zone Balmore C5 South (Easterhouse, Queenslie, Robroyston, Garthamlock)	6
Balmore Castlemilk	Distribution for Zone Balmore Castlemilk	6
Balmore C	Distribution for Zone Balmore C (South Airdrie, North Motherwell, Bellshill)	6
Balmore D	Distribution for Zone Balmore D (Kirkintilloch, Lenzie, Lennoxtown, Boness)	6
Balmore E	Distribution for Zone Balmore E (Linlithgow, Kirkliston, Winchburgh, Boness)	6
Balmore F	Distribution for Zone Balmore F (Bathgate, Armadale, North Livingston)	6
Balquidder	Distribution for Zone Balquhidder (Balquidder and Kinghouse)	6
Barra Western Isles	Distribution for Zone Barra WI (Isle of Barra Western Isles)	6
Bayhead Western Isles	Distribution for Zone Bayhead WI (Isle of Barra Western Isles)	6
Belmore	Distribution for Zone Belmore (Arrochar, Garelochhead, Kilcreggan, Rosneath)	6
Benbecula Western Isles	Distribution for Zone Benbecula WI (Benbecula between North and South Uist)	6
Black Esk Winterhope	Distribution for Zone Black Esk Winterhope (Gretna, East Riggs)	6
Black Esk	Distribution for Zone Black Esk (Lochmaben, Lockerbie, Annan)	6
Blairlinnans North	Distribution for Zone Blairlinnans North (Helensburgh, Dumbarton, Kilpatrick, Balloch, Bonhill)	6
Blairlinnans South	Distribution for Zone Blairlinnans South (Northwest Paisley, Bridge of Weir, Erskine, Port Glasgow)	6
Blairnamarrow	Distribution for Zone Blairnamarrow (Tomintoul, Lagganvoulin)	6
Boardhouse Orkney	Distribution for Zone Boardhouse Orkney (Stromness,Twatt NW Mainland Orkney)	6

Bonar Bridge	Distribution for Zone Bonar Bridge Regional (Bonar Bridge, Invershin north of Inverness)	6
Bonchester	Distribution for Zone Bonchester (Bonchester Bridge south of Hawick)	6
Bonnycraig	Distribution for Zone Bonnycraig (Peebles)	6
Bracadale Skye	Distribution for Zone Bracadale Skye (Bracadale West Skye)	6
Bradan A	Distribution for Zone Bradan A (Ayr, Dalmellington, Prestwick, Annbank, Hurlford)	6
Bradan B	Distribution for Zone Bradan B (South Kilmarnock, Irvine, Troon, Darvel)	6
Bradan C	Distribution for Zone Bradan C	6
Braemar	Distribution for Zone Braemar (Braemar Village)	6
Brig O'Turk	Distribution for Zone Brig O' Turk (Brig O Turk - West of Callander)	6
Broadford Skye	Distribution for Zone Broadford Skye (Broadford Isle of Skye)	6
Bunessan Mull	Distribution for Zone Bunessan Mull (Bunessan, Fionnphort Mull and Iona)	6
Burncrooks and Blairlinnans	Distribution for Zone Burncrooks and Blairlinnans	6
Burncrooks	Distribution for Zone Burncrooks (Clydebank, Bearsden, North Milngavie, Duntocher)	6
Campbeltown	Distribution for Zone Campbeltown (Campbeltown, Southend,Glenbarr)	6
Camphill	Distribution for Zone Camphill (West Kilbride, North Ardrossan, Kilbirnie, Beith, Dalry)	6
Camps	Distribution for Zone Camps (South Larkhall, North Lesmahagow, Abington, Strathaven)	6
Carbost Skye	Distribution for Zone Carbost Skye (Carbost, Portnalong, Drynoch on Skye)	6
Cargen	Distribution for Zone Cargen (New Abbey, Carsethorn, Kirkhouse south of Dumfries)	6
Carradale	Distribution for Zone Carradale (Carradale Village Mull of Kintyre)	6
Carron Valley A	Distribution for Zone Carron Valley A (Falkirk, Larbert, Polmont)	6
Carron Valley B	Distribution for Zone Carron Valley B (Denny, Bonnybridge, Kilsyth, Cumbernauld)	6

Castle Moffat	Distribution for Zone Castle Moffat (Haddington, Dunbar, East Linton, North Berwick)	6
Clatto East	Distribution for Zone Clatto East (East Dundee, Carnoustie, Monifieth)	6
Clatto West	Distribution for Zone Clatto West (North and west Dundee)	6
Colonsay	Distribution for Zone Colonsay (Island of Colonsay)	6
Corrie Arran	Distribution for Zone Corrie Arran (Corrie, Sannox - North east Arran)	6
Corsehouse	Distribution for Zone Corsehouse (Dunlop, Lugton, Stewarton)	6
Coulter	Distribution for Zone Coulter (Biggar, South Lanark, Forth, Carnwath)	6
Craighead	Distribution for Zone Craighead (Huntly Aberdeenshire)	6
Craighouse Jura	Distribution for Zone Craighouse (Craighouse on Jura)	6
Craigie	Distribution for Zone Mannofield/Turriff/Invercannie (Craigie - Whitecairns north east of Dyce)	6
Craignure Mull	Distribution for Zone Craignure Mull (Craignure, Lochdonhead on Mull)	6
Crianlarich	Distribution for Zone Crianlarich (Crianlarich)	6
Daer A	Distribution for Zone Daer A (Lanark, Hamilton,Shotts,Douglas, Wishaw,Salsburgh)	6
Daer B	Distribution for Zone Daer B (East Kilbride, Cambuslang, Burnside)	6
Daer Coulter	Distribution for Zone Daer Coulter (Motherwell, Craigneuk (Wishaw))	6
Dalmally	Distribution for Zone Dalmally (Dalmally ,Lochawe, and Stronmilchan)	6
Dervaig Mull	Distribution for Zone Dervaig Mull (Dervaig Village west of Tobermory Isle of Mull)	6
Dhu Loch Bute	Distribution for Zone Dhu Loch Bute (Rothesay, Colintraive, Kilchattan)	6
Dornoch	Distribution for Zone Dornoch (Dornoch north of Dornoch Firth Easter Ross)	6
Dougliehill	Distribution for Zone Dougliehill (south Port Glasgow, Broadfield, Boglestone, Bardrainey)	6
Durness	Distribution for Zone Durness (Durness east of Cape Wrath Sutherland)	6
Earlish Skye	Distribution for Zone Earlish Skye (Uig and Earlish North Skye)	6
Eday Orkney	Distribution for Zone Eday Orkney (Isle of Eday, Orkney)	6
Eela Water Shetland	Distribution for Zone Eela Water Shetland (North end of Mainland Shetland)	6

Finlas	Distribution for Zone Finlas (Luss, Gartocharn, Arden)	6
Forehill/Turriff	Distribution for Zone Forehill and Turriff	6
Forehill	Distribution for Zone Forehill (Peterhead, Cruden Bay, Ellon, St Combs, St Fergus)	6
Fort Augustus	Distribution for Zone Fort Augustus (Fort Augustus south end Loch Ness)	6
Fort William	Distribution for Zone Fort William (Fort William)	6
Geocrab Western Isles	Distribution for Zone Geocrab WI (South Harris Western Isles)	6
Gigha	Distribution for Zone Gigha (Island of Gigha West of Kintyre peninsula)	6
Glenconvinth	Distribution for Zone Glenconvinth (Beauly, Strathglass, Glenconvinth)	6
Glendale Skye	Distribution for Zone Glendale Skye (West of Dunvegan Skye)	6
Glendevon A	Distribution for Zone Glendevon A (Dunfermline, Kincardine, Kelty, Oakley)	6
Glendevon B	Distribution for Zone Glendevon B (Lochgelly, Cowdenbeath, Burntisland)	6
Glendevon/Glenfarg	Distribution for Zone Glendevon/Glenfarg/Kinnesswood (Glenrothes, Pittenweem, Crail, Leslie, North Leven)	6
Glenelg	Distribution for Zone Glenelg (Glenelg, miles west of Shiel Bridge)	6
GLENFARG KWOODBH A	Distribution for Zone Glenfarg/Kinnesswood A (Kinnesswood, Glenrothes South, Coaltown of Balgonie, Marckinch,Thornton, Wemyss, Buckhaven, Methil)	6
GLENFARG KWOODBH B	Distribution for Zone Glenfarg/Kinnesswood B (Kirkcaldy East, Central & South, Kinghorn)	6
Glenfarg	Distribution for Zone Glenfarg (Kinross, Milnathort, Glenfarg, Strathmiglo)	6
Glengap	Distribution for Zone Glengap (Gatehouse of Fleet, Kirkudbright)	6
Glenlatterach	Distribution for Zone Glenlatterach (Pluscarden south of Forres and Elgin)	6
Gorthleck	Distribution for Zone Gorthleck (Foyers,Errogie, east shore of Loch Ness)	6
Greenock	Distribution for Zone Greenock (Greenock, Gourock, Inverkip)	6
Herricks	Distribution for Zone Herricks (Ruthven, Cairnie north of Huntly)	6
Hillend	Distribution for Zone Hillend (Edinburgh south Fairmilehead, Loanhead, Bonnyrigg)	6
Hopes	Distribution for Zone Hopes (Gifford, West and East Saltoun, south of	6

	Haddington)	
Howden	Distribution for Zone Howden (Selkirk, Melrose, Lauder)	6
Hoy Calder	Distribution for Zone Hoy Calder (Armadale, Wick, Thurso, John O Groats)	6
Innerleithen	Distribution for Zone Innerleithen (Innerleithen, Walkerburn)	6
Inverary	Distribution for Zone Inverary (Inveraray, Furnace, Minard Kintyre Peninsula)	6
Invercannie	Distribution for Zone Invercannie (Banchory, Lumphannan)	6
Invergarry	Distribution for Zone Invergarry (Invergarry north of Fort William)	6
Invermoriston	Distribution for Zone Invermoriston (Invermoriston, west bank of Loch Ness)	6
Inverness	Distribution for Zone Inverness (Inverness)	6
Kaim Lochwinnoch	Distribution for Zone Kaim Lochwinnoch (Lochwinnoch, Kilmacolm)	6
Kenmore	Distribution for Zone Kenmore (Kenmore, Acharn, Taymouth)	6
Kettleton	Distribution for Zone Kettleton (Moniaive, Thornhill north of Dumfries)	6
Kilchoan	Distribution for Zone Kilchoan (Kilchoan village Ardnamurchan peninsula)	6
Killiecrankie	Distribution for Zone Killicrankie (Aberfeldy,Pitlochry,Calvine,Fortingall, Ballinluig)	6
Killin	Distribution for Zone Killin (Killin, west end of Loch Tay)	6
Killylour	Distribution for Zone Killylour (Dumfries, Cargenbridge)	6
Kilmelford	Distribution for Zone Kilmelford (Kilmelford Village south of Oban)	6
Kilmuir Skye	Distribution for Zone Kilmuir Skye (North of Uig on Skye)	6
Kinlochbervie	Distribution for Zone Kinlochbervie (Kinlochbervie Sutherland)	6
Kinlochewe	Distribution for Zone Kinlochewe (Kinlochewe Wester Ross)	6
Kinlochleven	Distribution for Zone Kinlochleven (Kinlochleven east of Glencoe)	6
Kinloch Rannoch	Distribution for Zone Kinloch Rannoch (Kinloch Rannoch, East end of loch Rannoch)	6
Kirbister Orkney	Distribution for Zone Kirbister Orkney (Kirkwall, South Ronaldsay)	6
Kirkmichael	Distribution for Zone Kirkmichael (Bridge of Cally and Kirkmichael Perthshire)	6
Kyle of Lochalsh	Distribution for Zone Kyle of Lochalsh (Kyle of Lochalsh)	6
Larchfield	Distribution for Zone Larchfield (East Dumfries)	6
Lerwick Shetland	Distribution for Zone Lerwick Shetland (Lerwick, Sumburgh and south of	6

	Mainland Shetland)	
Lintrathen	Distribution for Zone Lintrathen (Forfar,Kirriemuir, Blairgowrie, Flakland)	6
Loch Eck	Distribution for Zone Loch Eck (Dunoon, Stachur, Cairndow, Ardentinny, Innellan)	6
Lochaline	Distribution for Zone Lochaline (Lochaline north side of Sound of Mull)	6
Lochcarron	Distribution for Zone Lochcarron (Lochcarron village)	6
Lochearnhead	Distribution for Zone Lochearnhead (Lochearnhead)	6
Lochenkit	Distribution for Zone Lochenkit (Crocketford west of Dumfries)	6
Lochgoilhead	Distribution for Zone Lochgoilhead (Lochgoilhead)	6
Lochinvar	Distribution for Zone Lochinvar (Castle Douglas, New Galloway, Dalbeattie)	6
Lochinver	Distribution for Zone Lochinver (Lochinver Wester Ross)	6
Lochmaddy Western Isles	Distribution for Zone Lochmaddy WI (Lochmaddy North Uist)	6
Lochranza Arran	Distribution for Zone Lochranza Arran (Lochranza - north west Arran)	6
Lomond Hills BH Mix	Distribution for Zone Lomond Hills/Newton of Lathrisk/Knowshead (Cupar, St Andrews, Newport on Tay)	6
Lomond Hills	Distribution for Zone Lomond Hills (Falkland, Auchtermuchty, Freuchie)	6
Lumsden	Distribution for Zone Lumsden (Lumsden south of Dufftown)	6
Mallaig	Distribution for Zone Mallaig (Mallaig, Arisaig)	6
Mannofield East	Distribution for Zone Mannofield East (Aberdeen City Centre)	6
Mannofield North	Distribution for Zone Mannofield North (North Aberdeen, Northfield, Mastrick, Dyce)	6
Mannofield South	Distribution for Zone Mannofield South (South Aberdeen, Nigg, Altens, Cove Bay)	6
Mannofield West	Distribution for Zone Mannofield West (West Aberdeen Peterculter, Cults, Alford)	6
Manse Street	Distribution for Zone Manse St (Galashiels)	6
Marchbank A	Distribution for Zone Marchbank A (Currie,Balerno,South Livingston)	6
Marchbank B	Distribution for Zone Marchbank B (N Edinburgh Muirhouse, Granton,	6

	Cramond, Port of Leith)	
Milngavie C1	Distribution for Zone Milngavie C1 (Barrhead, Thornliebank)	6
Milngavie C2	Distribution for Zone Milngavie C2 (Glasgow Rutherglen, Shawfield, Croftfoot, Possilpark)	6
Milngavie C3	Distribution for Zone Milngavie C3 (Glasgow Cowcaddens, Carntyne, Port Dundas, Firhill)	6
Milngavie C4	Distribution for Zone Milngavie C4 (Glasgow Parkhead, Mount Vernon, Bridgeton, Dalmarnock)	6
Milngavie M1	Distribution for Zone Milngavie M1(Glasgow North, Maryhill, Ruchil, Gilshochil)	6
Milngavie M2	Distribution for Zone Milngavie M2 (Glasgow South, Langside, Crossmyloof, Shawlands)	6
Milngavie M3	Distribution for Zone Milngavie M3 (Glasgow Kelvinside, Ibrox, Dromoyne, Finnieston, Anderston)	6
Milngavie M4c	Distribution for Zone Milngavie M4c (Glasgow West End Yoker, Partick, Kelvingrove)	6
Milngavie M5 Renfrew	Distribution for Zone Milngavie M5 Renfrew (Renfrew, Arkleston, Williamsburgh)	6
Milngavie South Moorehouse	Distribution for Zone Milngavie South Moorehouse (Glasgow Sth Newton Mearns, Crookfur, Williamwood, Giffnock)	6
Moffat	Distribution for Zone Moffat (Moffat)	6
Muirdykes	Distribution for Zone Muirdykes (South Paisley, Johnston, Kilbarchan, Linwood, Howwood)	6
Neilston	Distribution for Zone Neilston (Neilston, Gateside, West Arthurlie, Uplawmoor, Holehouse)	6
Ness Western Isles	Distribution for Zone Ness WI (Port of Ness north end of Lewis)	6
Newcastleton	Distribution for Zone Newcastleton (Newcastleton south of Hawick)	6
Newmore B	Distribution for Zone Newmore B	6
Newmore	Distribution for Zone Newmore (Invergordon, Tain)	6

Orasay Western Isles	Distribution for Zone Orasay WI (Kintarvie, Balallan, Achmore South Lewis)	6
Osedale Skye	Distribution for Zone Osedale Skye (Dunvegan west of Skye)	6
Pateshill	Distribution for Zone Pateshill (North Bathgate, South Whitburn, Fauldhouse, Stoneyburn)	6
Penwhapple	Distribution for Zone Penwhapple (Girvan, Ballantrae)	6
Penwhirn	Distribution for Zone Penwhirn (South Stranraer, Portpatrick, Whithorn, Drummore)	6
Perth	Distribution for Zone Perth (Perth North Inch South Inch Woodlands)	6
Picketlaw South Moorehouse	Distribution for Zone Picketlaw/South Moorehouse (Mearns, Hazeldene, Kirkhill East Renfrewshire)	6
Picketlaw	Distribution for Zone Picketlaw (Eaglesham, Clarkston, Williamwood)	6
Port Charlotte Islay	Distribution for Zone Port Charlotte Islay (Port Charlotte, Portnahaven Island of Islay)	6
Raasay Skye	Distribution for Zone Raasay Skye (South west of island of Raasay)	6
Rawburn	Distribution for Zone Rawburn (Coldstream, Eyemouth, Duns, Greenlaw)	6
Ringford	Distribution for Zone Ringford (Kirkudbright)	6
Roberton	Distribution for Zone Roberton (Kelso, Jedburgh, Hawick)	6
Rosebery Castle Moffat	Distribution for Zone Rosebery/Castle Moffat (Musselburgh, Aberlady, Macmerry)	6
Rosebery Hopes	Distribution for Zone Rosebery/Hopes (Fountainhall south of Dalkeith)	6
Rosebery	Distribution for Zone Rosebery (Penicuik, Lasswade, Broughton, Dolphinton, Elsrickle)	6
Sanday Orkney	Distribution for Zone Sanday Orkney (Isle of Sanday Orkney)	6
Savalbeg	Distribution for Zone Savelbeg (Lairg Sutherland)	6
Scourie	Distribution for Zone Scourie (Scourie Sutherland)	6
Shieldaig	Distribution for Zone Shieldaig (Shieldaig south of Loch Torridon)	6
South Hoy Orkney	Distribution for Zone South Hoy Orkney (South end of Isle of Hoy Orkney)	6

South Moorehouse	Distribution for Zone South Moorehouse (Giffnock East Renfrewshire)	6
South Uist Western Isles	Distribution for Zone South Uist WI (Lochboisdale, Loch Skipport, South Uist)	6
Southdean	Distribution for Zone Southdean (Chesters, Palside, Southdean SE of Hawick)	6
Spynie	Distribution for Zone Spynie (Elgin and Forres)	6
Staffin Skye	Distribution for Zone Staffin Skye (Staffin, Elishadder, Flodigarry NE Skye)	6
Stoer	Distribution for Zone Stoer (Stoer north of Lochinver)	6
Stornoway Western Isles	Distribution for Zone Stornoway WI (Stornoway, Eye Peninsula, Isle of Lewis)	6
Storr Forest Skye	Distribution for Zone Storr Forest Skye (Portree, Kildonan, Borve, Edinbane, Skye)	6
Strathyre	Distribution for Zone Strathyre (Strathyre north of Callander)	6
Stronsay Orkney	Distribution for Zone Stronsay Orkney (Isle of Stronsay Orkney)	6
Strontian	Distribution for Zone Strontian (Strontian Ardnamurchan)	6
Suainaval Western Isles	Distribution for Zone Suainaval WI (Enaclete, Forsnaval West side of Lewis)	6
Tarbert Western Isles	Distribution for Zone Tarbert WI (Tarbert south end of Isle of Lewis)	6
Tarbert Argyll	Distribution for Zone Tarbert Argyll (Tarbert(Loch Fyne),Kennacraig, and Claonaig)	6
Taynuilt	Distribution for Zone Taynuilt (Taynuilt and Kilchrennan villages near Oban)	6
Teangue Skye	Distribution for Zone Teangue Skye (Teangue Sleat Peninsula South Skye)	6
Terregles	Distribution for Zone Terregles (Dumfries Town)	6
Tighnabruaich	Distribution for Zone Tighnabruaich (Tighnabruaich, Kames, Millhouse)	6
Tiree	Distribution for Zone Tiree (Island of Tiree)	6
Tobermory Mull	Distribution for Zone Tobermory Mull (Tobermory Salen Isle of Mull)	6
Tolsta Western Isles	Distribution for Zone Tolsta WI (Tolsta,north east of Isle of Lewis)	6
Tomatin	Distribution for Zone Tomatin (Tomatin village south of Inverness)	6
Tomich	Distribution for Zone Tomich (West of Loch Ness,south of river Affric)	6
Tomnavoulin	Distribution for Zone Tomnavoulin (Tomnavoulin north of Tomintoul)	6

Torra Islay	Distribution for Zone Torra Islay (Port Ellen, Bowmore, Bridgend on Islay)	6
Tullich	Distribution for Zone Tullich (Oban,Seil and Luing islands, Port Appin)	6
Turret/Balmore/Carron Valley	Distribution for Zone Turret/Balmore/Carron Valley (Grangemouth)	6
Turret A	Distribution for Zone Turret A (Dunblane, Cowie, Clackmannanshire)	6
Turret B	Distribution for Zone Turret B (Crieff Auchterarder)	6
Turret C	Distribution for Zone Turret C	6
Turriff	Distribution for Zone Turriff (Turriff, Fraserburgh,Aberchirder, Cullen,Portsoy)	6
Tyndrum	Distribution for Zone Tyndrum (Tyndrum and Clifton)	6
Ullapool	Distribution for Zone Ullapool (Ullapool, Loch Broom, Wester Ross)	6
Unst Shetland	Distribution for Zone Unst Shetland (Isle of Unst Shetland)	6
Waternish Skye	Distribution for Zone Waternish Skye (Hallistra,Hallin, Trumpan , north west Skye)	6
West Lewis Western Isles	Distribution for Zone West Lewis WI (Carloway, Great Bernera North West Lewis)	6
Westray Orkney	Distribution for Zone Westray Orkney (Isle of Westray, Orkney)	6
Whalsay Shetland	Distribution for Zone Whalsay Shetland (Isle of Whalsay Shetland)	6
Whitehillocks	Distribution for Zone Whitehillocks (Inverbervie and Laurencekirk Aberdeenshire)	6
Winterhope	Distribution for Zone Winterhope (Gretna)	6
Yarrowford	Distribution for Zone Yarrowford (Broadmeadows west of Selkirk)	6
Glencorse A	Distribution for Zone Glencorse A	6
Glencorse B	Distribution for Zone Glencorse B	6
Glencorse C	Distribution for Zone Glencorse C	6
Glencorse D	Distribution for Zone Glencorse D	6
Yell Shetland	Distribution for Zone Yell Shetland	6
Aviemore	Distribution for Zone Aviemore (Newtonmore, Grantown on Spey, Carrbridge)	6
Poolewe	Distributon for Zone Poolewe	6
Daer Camps A	Distribution for Zone Daer Camps A (north Lanark, south Lesmahagow, north	6

	Larkhall, Carluke)	
Daer Camps B	Distribution for Zone Daer Camps B (Uddingston, Viewpark, Blantyre, east Cambuslang)	6
Milngavie M5 Drumchapel North	Distribution for Zone Milngavie M5 Drumchapel (Glasgow Drumchapel, Bellahouston, Pollock, Crookston)	6
Milngavie M5 Drumchapel South	Distribution for Zone Milngavie M5 Drumchapel	6
Achmelvich	Distribution for Zone Achmelvich (Achmelvich north of Lochinver)	4
Achnasheen	Distribution for Zone Achnasheen (Achnasheen Wester Ross)	4
Alligin	Distribution for Zone Alligin (North shore of Loch Torridon Wester Ross)	4
Altnaharra	Distribution for Zone Altnaharra (Altnaharra west end of Loch Naver Sunderland)	4
Ardeonaig	Distribution for Zone Ardeonaig (Ardeonaig south of Loch Tay)	4
Ardvourlie Western Isles	Distribution for Zone Ardvourlie WI (Ardvourlie, south end of Isle of Lewis)	4
Arinagour Coll	Distribution for Zone Arinagour Coll (Arinagour on the island of Coll)	4
Arnisdale	Distribution for Zone Arnisdale (Arnisdale, north bank of Loch Hourn)	4
Beasdale	Distribution for Zone Beasdale (West of Beasdale station on road to Mallaig)	4
Carrick Castle	Distribution for Zone Carrick Castle (Carrick Castle - south of Lochgoilhead)	4
Carron Valley and Turret	Distribution for Zone Carron Valley and Turret	4
Carsphairn	Distribution for Zone Carsphairn (Carsphairn south of Dalmellington)	4
Claddich	Distribution for Zone Claddich (Cladich south bank of Loch Awe Argyll)	4
Cliasmol Western Isles	Distribution for Zone Cliasmol WI (Cliasmol south west of Isle of Lewis)	4
Crathie	Distribution for Zone Crathie (Crathie next to Balmoral Castle ,Deeside)	4
Dalchreichart	Distribution for Zone Dalcreichart (Dalchreichart, Glen Moriston west of Loch Ness)	4
Dalwhinnie	Distribution for Zone Dalwhinnie (Dalwhinnie on north of Pitlochry)	4

Diabeg	Distribution for Zone Diabeg (East shore of Loch Torridon Wester Ross)	4
Drimnin	Distribution for Zone Drimnin (Drimnin west of Lochaline)	4
Drumbeg	Distribution for Zone Drumbeg (North west of Loch Assynt Wester Ross)	4
Drumfearn Skye	Distribution for Zone Drumfearn Skye (Drumfearn south of Broadford Skye)	4
Elgol Skye	Distribution for Zone Elgol Skye (South of Cuillins Skye)	4
Fair Isle Shetland	Distribution for Zone Fair Isle Shetland (Fair Isle Shetland south of Mainland)	4
Fetlar Shetland	Distribution for Zone Fetlar Shetland (Isle of Fetlar Shetland)	4
Foula Shetland	Distribution for Zone Foula Shetland (Isle of Foula west of Mainland Shetland)	4
Glenuig	Distribution for Zone Glenuig (Glenuig Bay south of Arisaig)	4
Govig Western Isles	Distribution for Zone Govig WI (Govig south west of Isle of Lewis)	4
Hushinish Western Isles	Distribution for Zone Hushinish WI (Hushinish south west Isle of Lewis)	4
Inchlaggan	Distribution for Zone Inchlaggan (Inchlaggan west of Loch Garry, Inverness-shire)	4
Kilberry	Distribution for Zone Kilberry (Kilberry south west of Tarbert Loch Fyne)	4
Kilmaluag Skye	Distribution for Zone Kilmaluag Skye (Kilmaluag at northern tip of Skye)	4
Kylesku	Distribution for Zone Kylesku (NW shore Loch Glencoul Wester Ross)	4
Laggan Bridge	Distribution for Zone Laggan Bridge (Laggan village north of Dalwhinnie)	4
Laid	Distribution for Zone Laid (West Shore of Loch Eriboll Sutherland)	4
Meavaig Western Isles	Distribution for Zone Meavaig WI (Meavaig South west Lewis)	4
North Hoy Orkney	Distribution for Zone North Hoy Orkney (North end of Isle of Hoy Orkney)	4
North Ronaldsay Orkney	Distribution for Zone North Ronaldsay Orkney (North Ronaldsay Orkney)	4
Oykel Bridge	Distribution for Zone Oykel Bridge (Oykel Bridge Easter Ross)	4
Papa Stour Shetland	Distribution for Zone Papa Stour Shetland (Papa Stour west of Mainland Shetland)	4
Peninver	Distribution for Zone Peninver (Peninver village on Kintyre Peninsula)	4
Rhenigidale Western Isles	Distribution for Zone Rhenigidale WI (Rhenigidale east of Tarbert Harris Western Isles)	4

Rousay Orkney	Distribution for Zone Rousay School Orkney (Island of Rousay Orkney)	4
Saddell	Distribution for Zone Saddell (Saddell village Kintyre Peninsula)	4
Sanna	Distribution for Zone Sanna (Sanna and Portuark West Ardnamurchan)	4
Skerries Shetland	Distribution for Zone Skerries Shetland (Bruray, Housay, Grunay east of Mainland Shetland)	4
Strollamus Skye	Distribution for Zone Strollamus Skye (North of Broadford Skye)	4
Tarskavaig Skye	Distribution for Zone Tarskavaig Skye (Tarskavaig Sleat Peninsula South Skye)	4
Torridon	Distribution for Zone Torridon (East end Loch Torridon Wester Ross)	4
Torrin Skye	Distribution for Zone Torrin Skye (Torrin SW of Broadford on Skye)	4
Tweedsmuir	Distribution for Zone Tweedsmuir (Tweedsmuir north of Moffat)	4
Yarrowfeus	Distribution for Zone Yarrowfeus (Yarrowfeus, Yarrow west of Selkirk)	4
Lismore Primary	Distribution for Lismore	4

Table 7.2 Zones information

ZONE	SOURCE	CLORAMINATED	WTW	POPULATION	SW REGION	SOURCE TYPE
ACHARACLE	Allt Beithe		Acharacle	417	NORTH	SW
ACHILTIBUIE	Allt Ach A'Braighe		Achiltibuie	271	NORTH	SW
ACHMELVICH	Lochan Sgeireach		Achmelvich	88	NORTH	SW
ACHNASHEEN	Allt Achaidh Na Sine		Achnasheen	48	NORTH	SW
AFTON	Afton Res (upland)		Afton	44028	WEST	SW
ALEXANDRIA	Loch Finlas (upland reservoir), Carman		Alexandria	20626	WEST	SW
ALLIGIN	Abhainn Alligin		Alligin	67	NORTH	SW
ALTNAHARRA	Loch Buidhe		Altnaharra	21	NORTH	SW
AMLAIRD	Lochgoin (upland reservoir) Craigendunton		Amlaird	34874	WEST	SW
APPLECROSS	Allt Nan Corp, Applecross		Applecross	162	NORTH	SW
ARDEONAIG	stream / river		Ardeonaig	48	WEST	SW
ARDFERN	Loch Fada		Ardfern	195	NORTH	SW
ARDRISHAIG	Kilduskland Reservoir		Ardrishaig	5400	NORTH	SW
ARDVOURLIE WI	Vigadale River		Ardvourlie	27	NORTH	SW
ARINAGOUR	Loch Airidh Aon Oidhche		Arinagour	90	NORTH	SW
ARNISDALE	Allt An Fhuarain		Arnisdale	50	NORTH	SW
ASCOG BUTE	Loch Ascog		Ascog	5039	WEST	SW
ASSYNT	Loch Glass	CLORAMINATED	Assynt	30134	NORTH	SW
AUCHNEEL	Knockquhassen Reservoir Dindinnie Reservoir	CLORAMINATED	Auchneel	9351	SOUTH	SW

AULTBEA	Loch A'Bhaid Luachra		Aultbea	631	NORTH	SW
AVIEMORE	Aviemore Boreholes		Aviemore	10568	NORTH	GW
BACKIES	Loch Horn, Loch Lunndaidh	CLORAMINATED	Backies	4466	NORTH	SW
BADACHRO	Loch Braigh Horrisdale		Badachro	177	NORTH	SW
BADCAUL	Allt Airdeasaidh		Badcaul	136	NORTH	SW
BADENTINAN	Spey Boreholes, Dipple	CLORAMINATED	Badentinan	27927	EAST	GW
BALLYGRANT ISLAY	Loch Lossit		Ballygrant	320	NORTH	SW
BALMICHAEL ARRAN	Borehole		Balmichael	3753 (increased during tourist season)	WEST	GW
BALLATER	River Gairn, Ballater		Ballater	3722	EAST	SW
BALMORE A	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE B	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE C	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE C5 NORTH	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE C5 SOUTH	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE CAR VALLEY	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE CASTLEMILK	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE D	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALMORE E	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW

BALMORE F	Loch Lomond (lowland) Loch Katrine (upland)		Balmore	748568	WEST	SW
BALQUIDDER	Kirkton burn		Balquhidder	214	WEST	SW
BARRA WI	Loch An Duin		Barra	1160	NORTH	SW
BAYHEAD WI	Loch Mhic Gille Bhride		Bayhead	1018	NORTH	SW
BEASDALE	Beasdale Burn		Beasdale	8	NORTH	SW
BELMORE	Loch Sloy		Belmore	8333	WEST	SW
BENBECULA WI	Loch Eilean Iain		Benbecula	1602	NORTH	SW
BLACK ESK WINTERH	Black Esk Reservoir, Winterhope Reservoir		Black Esk/Winterhopes	3038	SOUTH	SW
BLACK ESK	Black Esk Reservoir		Black Esk	36027	SOUTH	SW
BLAIRLINNAN NORTH	Loch Lomond (lowland)		Blairlinnans	104769	WEST	SW
BLAIRLINNAN SOUTH	Loch Lomond (lowland)		Blairlinnans	104769	WEST	SW
BLAIRNAMARROW	local surface water and springs	CLORAMINATED	Blairnamarrow	335	EAST	SW
BOARDHOUSE ORK	Boardhouse Loch	CLORAMINATED	Boardhouse	559	EAST	SW
BONAR BRIDGE	Loch A'Ghobhair		Bonar Bridge	1428	NORTH	SW
BONCHESTER	SPRING		Bonchester	185	SOUTH	GW
BONNYCRAIG	Megget Reservoir		Bonnycraig	8853	SOUTH	SW
BRACADALE SKYE	Voaker Burn		Bracadale	220	NORTH	SW
BRADAN A	Loch Bradan Reservoir (upland) Derclach Loch		Bradan	184065	WEST	SW
BRADAN B	Loch Bradan Reservoir (upland) Derclach Loch		Bradan	184065	WEST	SW
BRADAN C	Loch Bradan Reservoir (upland) Derclach Loch		Bradan	184065	WEST	SW
BRAEMAR	Braemar, Auchendryne Burn		Braemar	480	EAST	SW
BRIG O TURK	Miltonglen Burn		Brig O'Turk	119	WEST	SW
BROADFORD SKYE	Allt A'Mhuillin, Broadford		Broadford	1025	NORTH	SW

BUNESSAN MULL	Loch Assapol		Bunessan	414	NORTH	SW
BURN BLAIR	Burncrooks/ Loch Lomond (lowland)		Burncrooks/Blairlinnans	51629	WEST	SW
BURNCROOKS	Burncrooks		Burncrooks	46400	WEST	SW
CAMPBELTOWN	Loch Auchalochy and Loch Ruan		Campbeltown	6482	NORTH	SW
CAMPHILL	Muirhead/Camphill (upland reservoir)		Camphill	40012	WEST	SW
CAMPS	Camps		Camps	43581	SOUTH	SW
CARBOST SKYE	Allt Ribhein		Carbost	361	NORTH	SW
CARGEN	Cargen Borehole		Cargen Borehole	2759	SOUTH	GW
CARRADALE	boreholes No 4 a set= 1large and 1 small		Carradale	510	NORTH	GW
CARRICK CASTLE	Carrick (river / burn)		Carrick Castle	88	WEST	SW
CARRON VAL TURRET	Carron Valley		Carron Valley	150000	WEST	SW
CARRON VALLEY A	Carron Valley		Carron Valley	150000	WEST	SW
CARRON VALLEY B	Carron Valley		Carron Valley	150000	WEST	SW
CARSPHAIRN	Benloch Burn		Carsphairn	78	SOUTH	SW
CASTLE MOFFAT	Whiteadder Res		Castle Moffat	33303	SOUTH	SW
CLADDICH	Bi-Cladich Burn		Cladich	10	NORTH	SW
CLATTO EAST	Lintrathen Loch, Backwater Reservoir		Clatto	83160	EAST	SW
CLATTO WEST	Lintrathen Loch, Backwater Reservoir		Clatto	96452	EAST	SW
CLIASMOL WI	Loch Nan Caor		Cliasmol	21	NORTH	SW
COLONSAY	Loch an Sgoltaire		Colonsay	104	NORTH	SW
CORRIE ARRAN	Corrie Intake (river / burn abstraction)		Corrie Membrane	330	WEST	SW
CORSEHOUSE	Corsehouse (upland reservoir) Whiteloch , Long Loch overland pipe as required		Corsehouse	11596	WEST	
COULTER	Coulter		Coulter	16934	SOUTH	SW
CRAIGHOUSE	River Abhainn A' Mhinisteir		Craighouse	104	NORTH	SW

CRAIGHEAD	Cairnford Bridge, Huntly, Clashmach Intake, Clashmach Spring, Clashmach Wellhead, Collonach Valley, Craighead Raw Water Res, Wellheads Farm, Huntly		Craighead	4856	EAST	
CRAIGIE	Mannofield/Turriff/Invercannie	CLORAMINATED	Mannofield/Turriff/Invercannie	54856	EAST	SW
CRAIGNURE MULL	River Scallastle		Craignure	199	NORTH	SW
CRATHIE	Crathie Springs		Crathie	30	EAST	GW
CRIANLARICH	Allt Coire Ardrain Burn		Crianlarich	185	WEST	SW
DAER A	Daer		Daer	94327	SOUTH	SW
DAER B	Daer		Daer	93861	SOUTH	SW
DAER CAMPS A	Daer & Camps		Daer & Camps	83493	SOUTH	SW
DAER CAMPS B	Daer & Camps		Daer & Camps	50771	SOUTH	SW
DAER COULTER	Daer & Coulter		Daer & Coulter	10593	SOUTH	SW
DALCREICHART	a river source called Allt Bail an Tuim Bhuidhe		Dalchreichart	81	NORTH	SW
DALMALLY	River Strae		Dalmally	439	NORTH	SW
DALWHINNIE	River Truim Well		Dalwhinnie	79	NORTH	GW
DERVAIG MULL	River Bellart		Dervaig	132	NORTH	SW
DHU LOCH BUTE	Dhu Loch		Dhu Loch	3731	WEST	SW
DIABEG	Allt Loch Roag		Diabeg	32	NORTH	SW
DORNOCH	Loch Lannsaidh,Loch Laoigh		Londornoch	2176	NORTH	SW
DOUGLIEHILL	Knocknairshill/Harelaw		Dougliehill	11694	WEST	SW
DRIMNIN	Abhainn Mhungasdail		Drimnin	23	NORTH	GW
DRUMBEG	Lochan Daraich		Drumbeg	71	NORTH	SW
DRUMFEARN	Loch an Lasgaich		Drumfearn	727	NORTH	SW

DURNESS	Loch Borralie		Durness Keoldale	282	NORTH	SW
EARLISH SKYE	Abhuinn Dhubh		Earlish/Uig	356	NORTH	SW
EDAY ORK	borehole		Eday	121	EAST	GW
EELA WATER SHET	Eela Water, Roer Water, Moshella Loch	CLORAMINATED	Eela Water	5538	EAST	SW
FAIR ISLE SHET	Vaadal Burn Dam		Fair Isle	69	EAST	SW
ELGOL	Allt A'Ghoirtein		Elgol	67	NORTH	SW
FETLAR SHET	Skutes Water		Fetlar	85	EAST	SW
FINLAS	Finlas		Finlas	1050	WEST	SW
FOREHILL TURRIFF	river ugle/ blackhill borehole/river Deveron		Forehill/Turriff	3924	EAST	SW/GW
FOREHILL	river ugle/ blackhill borehole		Forehill	29000	EAST	SW/GW
FORT AUGUSTUS	Loch Tarff		Fort Augustus	580	NORTH	SW
FORT WILLIAM	Camisky Wellfield (River Lochy)	CLORAMINATED		13588	NORTH	SW
FOULA SHET	Springs Burn Dam		Foula	71	EAST	GW
GEOCARB WI	Loch Geimisgarave		Geocrab	859	NORTH	SW
GIGHA	Mill Loch		Gigha	110	NORTH	SW
GLENCONVINTH	Loch Bruicheach	CLORAMINATED	Glenconvinth	5290	NORTH	SW
GLENCORSE A	Megget, Talla, Fruid (Comp), Glencorse, Loganlea (Comp),	CLORAMINATED	Glencorse	99194	SOUTH	SW
GLENCORSE B	Megget, Talla, Fruid (Comp), Glencorse, Loganlea (Comp),	CLORAMINATED	Glencorse	83111	SOUTH	SW
GLENCORSE C	Megget, Talla, Fruid (Comp), Glencorse, Loganlea (Comp),	CLORAMINATED	Glencorse	95553	SOUTH	SW
GLENCORSE D	Megget, Talla, Fruid (Comp), Glencorse, Loganlea (Comp),	CLORAMINATED	Glencorse	89014	SOUTH	SW
GLENDALE SKYE	Hamara River		Glendale	317	NORTH	SW
GLENDEVON A	Upper Glendevon Res, Lower Glendevon Res, Glensherup Res, Castlehill Res,		Glendevon	92601	EAST	

	Frandy Burn					
GLENDEVON B	Upper Glendevon Res, Lower Glendevon Res, Glensherup Res, Castlehill Res, Frandy Burn		Glendevon	38470	EAST	
GLENDEVON GLENFARG	Glenfarg / Glendevon		Glenfarg / Glendevon	60468	EAST	SW
GLENELG	Loch A'Mhuilinn		Glenelg	171	NORTH	SW
GLENFARG KBH A	Glenfarg Res, River Earn, Water of May, Slateford Burn		Glenfarg	48892	EAST	SW
GLENFARG KBH B	Glenfarg Res, River Earn, Water of May, Slateford Burn		Glenfarg	41156	EAST	SW
GLENFARG	Glenfarg Res, River Earn, Water of May, Slateford Burn		Glenfarg	21659	EAST	SW
GLENGAP	Loch Whinyeon		Glengap	3485	SOUTH	SW
GLENLATTERACH	Glenlatterach	CLORAMINATED	Glenlatterach	1492	EAST	SW
GLENUIG	Loch Bealach Na Garoithe		Glenuig	31	NORTH	SW
GOVIG WI	Loch Geodha Beag, (Airde Beaga)		Govig	9	NORTH	SW
GREENOCK	Loch Thom (upland reservoir)		Greenock	66083	WEST	SW
HERRICKS	Balloch Springs Herricks, Birkenburn Herricks,Burn of Davidstone Keith, Herricks Intake, Patties Croft, Herricks		Herricks	5477	EAST	SW
HILLEND	#N/A		#N/A	#N/A	#N/A	#N/A
HOPES	Hopes Reservoir, Fall Burn		Hopes	1941	SOUTH	SW
HOWDEN	Boreholes at Howden		Howden	21849	SOUTH	GW
HOY CALDER	Loch Calder	CLORAMINATED	Calder & Hoy	26861	#N/A	SW
HUSHINISH WI	Hushinish Borehole		Hushinish	7	NORTH	SW
INCHLAGGAN	Allt Gharbh		Inchlaggan	10	NORTH	SW
INNERLEITHEN	Howford Borehole		Innerleithen	3711	SOUTH	GW
INVERARY	Stellaire Ban Loch, Loch Rigeachan		Inveraray	1132	NORTH	SW

INVERCANNIE	Cairnton, River Dee	CLORAMINATED	Invercannie	24993	EAST	SW
INVERGARRY	Invergarry HEB Intake		Invergarry	183	NORTH	SW
INVERMORISTON	Loch Ness		Invermoriston	108	NORTH	SW
INVERNESS	Loch Ashie (20%), Loch Duntelchaig (80%)	CLORAMINATED	Inverness	68750	NORTH	SW
KAIM LOCHWINNOCH	Kaim		Kaim	7613	WEST	SW
KENMORE	Kenmore Borehole		Kenmore	263	EAST	GW
KETTLETON	Kettleton Reservoir, Kettleton Borehole		Kettleton	9206	SOUTH	SW
KILBERRY	Allt Dail A'Chairn River		Kilberry	17	NORTH	SW
KILCHOAN	Abhuinn Chro Bheinn		Kilchoan	140	NORTH	SW
KILLIECRANKIE	Allt Girnaig		Killiecrankie	7004	EAST	SW
KILLIN	Allt Glas/Achmore Burn		Killin	854	WEST	SW
KILLYLOUR	Glenkiln Reservoir		Killylour	313	SOUTH	SW
KILMALUAG SKYE	Kilmaluag Spring		Kilmaluag	72	NORTH	GW
KILMELFORD	Loch a Phearsain		Kilmelford	832	NORTH	SW
KILMUIR	Kilmuir Spring		Kilmuir	250	NORTH	GW
KINLOCH RANNOCH	Kinloch Rannoch Borehole		Kinloch Rannoch	261	EAST	GW
KINLOCHBERVIE	Loch Na Claise Carnaich		Kinlochbervie	457	NORTH	SW
KINLOCHEWE	Allt a Chuirn		Kinlochewe	108	NORTH	SW
KINLOCHLEVEN	Allt Coire Mhorair		Kinlochleven	911	NORTH	SW
KIRBISTER ORK	Kirbister loch	CLORAMINATED	Kirbister	4848	EAST	SW
KIRKMICHAEL	Kirkmichael Intake	CLORAMINATED	Kirkmichael	315	EAST	SW
KYLE OF LOCHALSH	Loch Achaid Na Hinnich, Allt Gleann Udalain	CLORAMINATED	Kyle of Lochalsh	2688	NORTH	SW
KYLESKU	Unapool Burn		Kylesku	38	NORTH	SW
LAGGAN BRIDGE	Laggan Bridge Boreholes		Laggan Bridge	55	NORTH	SW

LAID	Allt An Lagain		Laid	33	NORTH	SW
LARCHFELD	Larchfield Borehole		Larchfield	6632	SOUTH	GW
LERWICK SHET	Sandy Loch, Brindister Loch	CLORAMINATED	Lerwick, Sandy Loch	12906	EAST	SW
LINTRATHEN	Backwater Reservoir Lintrathen Loch		Lintrathen	89985	EAST	SW
LISMORE SCHOOL	boreholes		lismore primary	14	NORTH	GW
LOCH ECK	Loch Eck		Loch Eck	13243	WEST	SW
LOCHALINE	Allt Achadh Forsa		Lochaline	181	NORTH	SW
LOCHCARRON	Loch A'Choire Leith	CLORAMINATED	Lochcarron	787	NORTH	SW
LOCHEARNHEAD	Burn of Ample		Lochearnhead	368	WEST	SW
LOCHENKIT	Lochenkit Reservoir		Lochenkit	1207	SOUTH	SW
LOCHGOILHEAD	Lochgoilhead (upland river / burn intake)		Lochgoilhead Membrane	274	WEST	SW
LOCHINVAR	Lochinvar Reservoir		Lochinvar	12082	SOUTH	SW
LOCHINVER	Loch Bad Na Goibhre		LOCHINVAR	501	SOUTH	SW
LOCHMADDY WI	Loch Fada, Loch Nan Geadh		Lochmaddy	584	NORTH	SW
LOCHRANA ARRAN	Lochranza (river / burn)		Lochranza	380	WEST	SW
LOMOND HILLS BHS	Holl Res, Ballo Res, Harperleas Res, Drumain Res, Arnot Res		Lomond Hills	51434	EAST	
LOMOND HILLS	Holl Res, Ballo Res, Harperleas Res, Drumain Res, Arnot Res		Lomond Hills	4636	EAST	
LUMSDEN	Lumsden Borehole		Lumsden	424	EAST	GW
MALLAIG	Loch Eireagoraidh		Mallaig	1454	NORTH	SW
MANNOFIELD EAST	Inchgarth + Cairnton, River Dee	CLORAMINATED	Mannofield/ Invercannie	55161	EAST	SW
MANNOFIELD NORTH	Inchgarth + Cairnton, River Dee	CLORAMINATED	Mannofield/ Invercannie	44067	EAST	SW
MANNOFIELD SOUTH	Inchgarth + Cairnton, River Dee	CLORAMINATED	Mannofield/ Invercannie	65732	EAST	SW
MANNOFIELD WEST	Inchgarth + Cairnton, River Dee	CLORAMINATED	Mannofield/ Invercannie	66467	EAST	SW
MANSE ST	Knowsedean Res,Caddon Water (Comp)		Manse St Galashiels	9359	SOUTH	

	Glentanner Water (Comp)					
MARCHBANK A	Megget,North Pentland Springs (Not in Use)	CLORAMINATED	Marchbank	59012	SOUTH	SW
MARCHBANK B	Megget,North Pentland Springs (Not in Use)	CLORAMINATED	Marchbank	61211	SOUTH	SW
MEAVAIG WI	Loch Braigh Na Lice		Meavaig	7	NORTH	SW
MILNGAVIE C1	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE C2	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE C3	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE C4	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M1	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M2	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M3	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M4C	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M5 DRUMN	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M5 DRUMS	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE M5 REFRW	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MILNGAVIE SOUTH MO	Loch Katrine (Loch Arklet and Glen Finglas Reservoir) (upland reservoir)		Milngavie	592123	WEST	SW
MOFFAT	Moffat (Dyke Farm) Borehole		MOFFAT	3114	SOUTH	GW

MUIRDYKES	Barcraigs/Rowbanks		Muirdykes	83451	WEST	SW
NEILSTON	Long Loch (upland reservoir)		Neilston	8619	WEST	SW
NESS WI	Loch Hatravat		Ness	1181	NORTH	SW
NEWCASTLETON	Spring		Newcastleton	793	SOUTH	GW
NEWMORE B	River Glass, Redburn	CLORAMINATED	Newmore	13572	NORTH	SW
NEWMORE	River Glass, Redburn	CLORAMINATED	Newmore	13572	NORTH	SW
NORTH HOY ORK	Sandy Loch		North Hoy	46	EAST	SW
NORTH RONALDSAY	Spring		North Ronaldsay	70	EAST	SW
ORASAY WI	Loch Orasay	CLORAMINATED	North Lochs	2341	NORTH	SW
OSEDALE SKYE	Osedale River		Osedale	605	NORTH	SW
OYKEL BRIDGE	Oykel Bridge Borehole		Oykel Bridge	9	NORTH	GW
PAPA STOUR SHET	Gorda Water		Papa Stour	33	EAST	SW
PATESHILL	Baddingsgill Res, West Water Res	CLORAMINATED	Pateshill	58803	SOUTH	SW
PENINVER	Spring intake		Peninver	96	NORTH	SW
PENWHAPPLE	Penwhapple Reservoir		Penwhapple	8900	WEST	SW
PENWHIRN	Penwhirn Reservoir	CLORAMINATED	Penwhirn	19520	SOUTH	SW
PERTH	River Tay Intake		Perth	51020	EAST	SW
PICKETLAW S MOORE	Loch Craig/Loch Bennan		South Moorhouse	12023	WEST	SW
PICKETLAW	Dunwan (upland reservoir)		Picketlaw	25987	WEST	SW
POOLEWE	River Ewe		Poolewe	1236	#N/A	SW
PORTCHARLOTTE	Loch Gearach		Port Charlotte	700	NORTH	SW
RAASAY SKYE	Loch Na Meilich		Raasay	174	NORTH	SW
RAWBURN	Watchwater Reservoir,Dye River (Comp) Slighhouses Borehole (Comp)	CLORAMINATED	Rawburn	17148	SOUTH	SW
RHENIGIDALE WI	Loch an Druim Caol		Rhenigidale	7	NORTH	SW
RINGFORD	Boreholes		Ringford	#N/A	SOUTH	GW
ROBERTON	Alemoor Reservoir	CLORAMINATED	Roberton	35421	SOUTH	SW

ROSEBERY CAST MOFF	Rosebery/castle moffat		Rosebery/castle moffat	200000	SOUTH	SW
ROSEBERY HOPES	Rosebery/Hopes		Rosebery/Hopes	200000	SOUTH	SW
ROSEBERY	Reservoir		Rosebery	200000	SOUTH	SW
ROSEBERY A	Megget Res Gladhouse Res		Rosebery	56473	SOUTH	SW
ROSEBERY B	Megget Res Gladhouse Res		Rosebery	46532	SOUTH	SW
ROUSAY SCHOOL	borehole		Rousay	39	EAST	GW
SADDELL	2 Boreholes		Saddell	36	NORTH	GW
SANDAY ORK	Bea Loch		Sanday	11680	EAST	SW
SANNA	Allt Sanna		Sanna	43	NORTH	SW
SAVALBEG	Loch Beannach		Savalbeg	#N/A	NORTH	SW
SCOURIE	Loch Brishimi, Loch Mhichie		Scourie	159	SOUTH	SW
SHIELDAIG	Abhainn Ceann-Locha		Shieldaig	119	NORTH	SW
SKERRIES SHET	Skerries Gathering Area		Skerries	76	EAST	SW
SOUTH HOY ORK	Loch Heldale Water		South Hoy	421	EAST	SW
SOUTH MOOREHOUSE	Loch Craig/Loch Bennan		South Moorhouse	12023	WEST	SW
SOUTH UIST WI	Loch Iarras		Stoneybridge	1563	NORTH	SW
SOUTHDEAN	Spring		Southdean Mill	185	SOUTH	GW
SPYNIE	Spey Boreholes, Dipple, Glenlatterach	CLORAMINATED	Glenlatterach + Badentinan	27927	EAST	SW/GW
STAFFIN SKYE	Tobar Na Slainte Spring		Staffin	521	NORTH	GW
STOER	Loch Poll An Droighinn		Stoer	145	NORTH	SW
STORNOWAY WI	Loch Orasay	CLORAMINATED	North Lochs	2341	NORTH	SW
STORR FOREST SKYE	Storr Springs, Forest Springs		Storr Forest	3438	NORTH	GW
STRATHYRE	Allt Creagin (stream / river)		Strathyre	244	WEST	GW
STROLLAMUS SKYE	Allt Na Teangaidh		Strollamus	78	NORTH	SW
STRONSAY ORK	borehole		Stronsay	356	EAST	GW
STRONTIAN	Strontian River		Strontian	321	NORTH	SW
SUAINAVAL WI	Loch Bealach Euna Clibh	CLORAMINATED	Uig	343	NORTH	SW

TARBERT WI	Loch Braich Na h-Imrich		Tarbert Arg	1011	NORTH	SW
TARBERT	Loch a Chaorun		Tarbert Arg	1730	NORTH	SW
TAYNUILT	Loch an Droighinn and Loch an Leoid		Kilchrenan	97	NORTH	SW
TEANGUE SKYE	Loch Mhic Charmhicheil		Teangue	727	NORTH	SW
TERREGLES	Terregles (Manse Road) Borehole		Terregles	26507	SOUTH	GW
TIGHNABRUAICH	Tighnabruaich (upland reservoir craignafeoch)		Tighnabruaich	815	WEST	SW
TIREE	6 Boreholes. (No 3 High Fe ,No 7 low flow)		Tiree	770	NORTH	GW
TOBERMORY MULL	Loch Peallach		Tobermory	1347	NORTH	SW
TOLSTA WI	Loch Ionadagro	CLORAMINATED	Back Tolsta	1815	NORTH	SW
TOMATIN	Tomatin Borehole		Tomatin	357	NORTH	GW
TOMICH	Tomich Borehole		Tomich	286	NORTH	GW
TOMNAVOULIN	spring		Tomnavoulin	120	EAST	SW
TORRA ISLAY	River intake from LOCH BEINN URANRAIDH		Torra	1881	NORTH	SW
TORRIDON	Torridon Boreholes		Torridon	70	NORTH	GW
TORRIN SKYE	Allt Slapin		Torrin	78	NORTH	SW
TULLICH	Gleann a Bherraidh augmented from Loch Nell		Tullich	12351	NORTH	SW
TURR BALMR CARRONV	Loch Turret		Turret	96581	WEST	SW
TURRET A	Loch Turret		Turret	100000	WEST	SW
TURRET B	Loch Turret		Turret	100000	WEST	SW
TURRET C	Loch Turret		Turret	100000	WEST	SW
TURRIFF	River Deveron	CLORAMINATED	Turriff	48054	EAST	SW
TWEEDSMUIR	Talla Reservoir , Fruid Res (Comp)		Tweedsmuir	36	SOUTH	SW
TYNDRUM	Crom Allt (stream / burn)		Tyndrum	154	WEST	SW
ULLAPOOL	Ullapool Boreholes		Ullapool	1746	NORTH	GW
UNST SHET	Helliers Water, Loch of Watlee		Unst	655	EAST	SW

WATERNISH SKYE	Lusta Burn, Sein Burn		Waternish	256	NORTH	SW
WEST LEWIS WI	Loch Fasgro	CLORAMINATED	West Lewis	3096	NORTH	SW
WHALSAY SHET	Bu Water, Huxter Loch		Whalsay	1037	EAST	SW
WESTRAY ORK	Loch Saintear		Westray	478	EAST	SW
WHITEHILLOCKS	Loch Lee		Whitehillocks	22256	EAST	SW
WINTERHOPE	Winterhope Reservoir		Winterhope	1984	SOUTH	SW
YARROWFEUS	Borehole		Yarrowfeus	63	SOUTH	GW
YARROWFORD	Borehole		Yarrowford	70	SOUTH	GW
YELL SHET	#N/A	CLORAMINATED	#N/A	#N/A	EAST	#N/A

Table 7.3 WTWs treatment processes information

WTW	Floculation	Hypo	Membrane treatment	Clarification /Sedimentation	Flotation	RGF	Pressure Filters	Slow Sand Filters	GAC Filters	pH Adjustment	Phosphate dosing	Ozonation	Manganese removal
Acharacle			MB					SS	CF				
Achiltibuie		HC	MB							PH			
Achmelvich		HC							CF	PH			
Achnasheen		HC	MB							PH			
Afton	FL	HC		CS		RG				PH	PB		
Alexandria	FL				FS	RG				PH	PB		MN
Alligin		HC	MB							PH			
Altnaharra		HC	MB							PH			
Amlaird	FL				FS	RG				PH	PB		
Applecross		HC	MB							PH			
Ardeonaig		HC	MB							PH			
Ardfern		HC	MB							PH			
Ardrishaig	FL	HC			FS	RG				PH	PB		MN
Ardvourlie		HC	MB							PH			
Arinagour		HC	MB							PH			
Arnisdale		HC							CF				
Ascog		HC		CS			PF	SS		PH	PB		MN

Assynt	FL						PF			PH	PB		
Auchneel	FL	HC		CS		RG				PH	PB		MN
Aultbea		HC	MB							PH			
Aviemore	FL	HC	MB							PH	PB		
Backies		HC	MB							PH	PB		
Badachro		HC	MB							PH			
Badcaul		HC	MB							PH			
Badentinan										PH			
Ballygrant		HC	MB							PH			
Balmichael		HC											
Ballater		HC					PF			PH	PB		
Balmore	FL					RG				PH	PB		
Balquhidder		HC	MB							PH			
Barra	FL	HC					PF			PH			
Bayhead	FL	HC		CS			PF			PH			
Beasdale		HC							CF				
Belmore	FL				FS	RG				PH	PB		MN
Benbecula	FL	HC					PF			PH			
Black Esk	FL			CS		RG				PH	PB		
Blairlinnans	FL					RG				PH	PB		
Blairnamarrow		HC	MB							PH			
Boardhouse	FL	HC		CS		RG				PH			
Bonar Bridge		HC	MB							PH			
Bonchester		HC											
Bonnycraig	FL						PF			PH	PB		

Bracadale		HC	MB				PF			PH			
Bradan	FL				FS	RG				PH	PB		MN
Braemar		HC					PF			PH	PB		
Brig O'Turk		HC	MB							PH			
Broadford		HC	MB							PH			
Bunessan		HC	MB							PH			
Burncrooks	FL			CS		RG				PH			
Campbeltown	FL				FS	RG				PH	PB		MN
Camphill	FL			CS		RG				PH	PB		MN
Camps	FL				FS	RG				PH	PB		MN
Carbost		HC	MB							PH			
Cargen Borehole		HC									PB		
Carradale		HC	MB							PH			
Carrick Castle		HC	MB							PH			
Carron Valley	FL				FS	RG				PH	PB		
Carsphairn		HC	MB							PH			
Castle Moffat	FL			CS			PF			PH	PB		
Cladich		HC	MB							PH			
Clatto	FL					RG				PH			
Cliasmol		HC	MB							PH			
Colonsay		HC	MB							PH			
Corrie Membrane		HC	MB							PH			
Corsehouse	FL			CS		RG				PH	PB		

Coulter	FL	HC			FS	RG				PH	PB		MN
Craighouse		HC	MB							PH			
Craighead	FL	HC			FS		PF			PH	PB		
Craignure		HC						SS					
Crathie		HC	MB							PH			
Crianlarich		HC	MB							PH			
Daer	FL			CS		RG				PH	PB		
Dalchreichart		HC							CF				
Dalmally		HC	MB				PF			PH			
Dalwhinnie		HC								PH			
Dervaig		HC	MB							PH			
Dhu Loch	FL	HC			FS	RG				PH	PB		MN
Diabeg		HC	MB							PH			
Londornoch	FL	HC			FS	RG				PH	PB		
Dougliehill	FL				FS	RG				PH			
Drimnin		HC	MB							PH			
Drumbeg		HC	MB							PH			
Drumfearn		HC							CF	PH			
Durness Keoldale		HC						SS					
Earlish/Uig		HC	MB							PH			
Eday		HC											
Eela Water	FL	HC		CS		RG				PH			
Fair Isle		HC							CF				
Elgol		HC							CF				

Fetlar		HC							CF				
Finlas	FL				FS	RG				PH	PB		MN
Forehill/Turriff	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Forehill	FL			CS		RG				PH			MN
Fort Augustus		HC					PF		CF		PB		
Foula		HC							CF				
Geocrab	FL	HC					PF			PH			
Gigha		HC	MB						CF	PH			
Glenconvinth	FL	HC				RG				PH	PB		
Glencorse	FL	HC		CS	FS					PH	PB		
Glendale		HC	MB							PH			
Glendevon	FL					RG				PH	PB		
Glenelg		HC	MB							PH			
Glenfarg	FL				FS	RG				PH	PB	OZ	
Glengap	FL	HC			FS	RG				PH	PB		MN
Glenlatterach	FL			CS			PF			PH			
Glenuig		HC	MB							PH			
Govig		HC	MB							PH			
Greenock	FL				FS	RG				PH	PB		
Herricks	FL	HC			FS	RG				PH			
Hopes		HC					PF			PH	PB		
Howden		HC	MB							PH	PB		
Hushinish		HC							CF				

Inchlaggan		HC	MB							PH			
Innerleithen		HC									PB		
Inveraray	FL	HC			FS	RG				PH	PB		MN
Invercannie	FL		MB							PH			
Invergarry		HC	MB							PH			
Invermoriston		HC							CF	PH			
Inverness		HC	MB							PH	PB		
Kaim	FL				FS	RG				PH	PB		
Kenmore		HC								PH	PB		
Kettleton	FL	HC				RG				PH	PB		
Kilberry		HC	MB							PH			
Kilchoan		HC							CF	PH			
Killiecrankie	FL				FS	RG				PH	PB		
Killin	FL	HC	MB		FS	RG				PH			
Killylour	FL	HC					PF			PH			
Kilmaluag		HC											
Kilmelford		HC	MB							PH			
Kilmuir		HC											
Kinloch Rannoch		HC								PH	PB		
Kinlochbervie		HC	MB							PH			
Kinlochewe		HC							CF				
Kinlochleven		HC	MB							PH	PB		
Kirbister	FL	HC			FS	RG				PH			
Kirkmichael		HC	MB							PH			
Kyle of		HC	MB				PF			PH	PB		

Lochalsh													
Kylesku		HC	MB							PH			
Laggan Bridge		HC											
Laid		HC	MB							PH			
Larchfield													
Lerwick, Sandy Loch	FL				FS	RG				PH			
Lintrathen	FL					RG				PH			
lismore primary		HC					PF			PH			
Loch Eck	FL					RG				PH	PB		
Lochaline		HC							CF				
Lochcarron		HC							CF	PH			
Lochearnhead		HC	MB							PH			
Lochenkit	FL	HC		CS		RG				PH	PB		
Lochgoilhead Membrane		HC	MB							PH	PB		
Lochinvar	FL				FS	RG				PH	PB		MN
Lochmaddy	FL	HC					PF			PH			
Lochranza		HC	MB							PH			
Lomond Hills	FL					RG				PH	PB		
Lumsden		HC											
Mallaig		HC	MB							PH	PB		
Manse St Galashiels	FL			CS		RG				PH	PB		
Marchbank	FL				FS	RG				PH	PB		
Meavaig		HC	MB							PH			

Milngavie	FL	HC				RG				PH	PB		
Moffat		HC									PB		
Muirdykes	FL				FS	RG				PH	PB		
Neilston	FL			CS		RG			CF	PH			
Ness	FL	HC					PF			PH			
Newcastleton		HC											
Newmore	FL	HC		CS		RG				PH	PB		
North Hoy		HC	MB							PH			
North Ronaldsay		HC											
North Lochs	FL	HC		CS			PF			PH			
Osedale		HC		CS				SS	#N/A	#N/A	#N/A	#N/A	#N/A
Oykel Bridge		HC					PF			PH			
Papa Stour		HC							CF				
Pateshill	FL			CS		RG				PH	PB		
Peninver		HC					PF						
Penwhapple	FL				FS	RG				PH	PB		
Penwhirn	FL				FS	RG				PH			MN
Perth	FL	HC				RG				PH	PB		
South Moorhouse	FL				FS	RG				PH	PB		
Picketlaw	FL				FS	RG				PH	PB		
Poolewe	#N/A	#N/A	MB	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Port Charlotte	FL	HC		CS		RG				PH			MN
Raasay		HC						SS	CF	PH			
Rawburn	FL			CS			PF			PH	PB		
Rhenigidale		HC	MB							PH			

Ringford		HC									PB		
Roberton	FL	HC		CS		RG				PH	PB		
Rosebery	FL				FS	RG				PH	PB		
Rousay		HC											
Saddell		HC								PH			
Sanday	FL	HC			FS	RG			CF	PH			
Sanna		HC											
Savalbeg	FL	HC					PF			PH			
Scourie		HC						SS					
Shieldaig		HC											
Skerries		HC	MB							PH			
South Hoy		HC	MB							PH			
South Moorhouse	FL				FS	RG				PH	PB		
Stoneybridge	FL	HC					PF			PH			
Southdean Mill		HC				RG							
Staffin		HC											
Stoer		HC							CF				
North Lochs	FL	HC		CS			PF			PH			
Storr Forest		HC											
Strathyre		HC	MB							PH			
Strollamus		HC							CF	PH			
Stronsay		HC											
Strontian		HC	MB							PH			
Uig	FL	HC					PF			PH			
Tarbert Arg	FL	HC			FS	RG				PH	PB		MN
Kilchrenan		HC	MB							PH			
Teangue		HC	MB							PH			
Terregles		HC											

Tighnabruaich		HC	MB							PH	PB		
Tiree		HC				RG				PH			MN
Tobermory	FL	HC			FS	RG				PH	PB		
Back Tolsta	FL	HC					PF			PH			
Tomatin		HC								PH			
Tomich		HC								PH			
Tomnavoulin		HC	MB							PH			
Torra	FL	HC		CS		RG				PH	PB		MN
Torridon		HC								PH			
Torrin		HC								PH			
Tullich									CF	PH	PB	OZ	
Turret	FL			CS		RG				PH	PB		
Turriff	FL			CS		RG				PH	PB		
Tweedsmuir		HC				RG			CF				
Tyndrum		HC	MB							PH			
Ullapool		HC											
Unst		HC							CF				
Waternish		HC	MB							PH			
West Lewis	FL	HC					PF			PH			
Whalsay		HC					PF			PH			
Westray	FL	HC			FS	RG				PH			
Whitehillocks	FL			CS		RG				PH			
Winterhope	FL				FS	RG				PH	PB		MN
Yarrowfeus		HC								PH			
Yarrowford		HC											
yell shet south	FL	HC		CS				SS		PH			

yell shet mid	FL	HC						SS		PH			

Where:
Hypo: The sites use Sodium Hypochlorite rather than gas however lots of sit are moving to Hypo at the moment so this could be out of date.
RGF: Rapidy Gravity FilterGAC: Granular Activated Carbon filter

APPENDIX B: Supporting information for Chapter 4.

Table 7.4 HAA5 (µg/L) concentrations according to the region of Scotland

	HAA_5 (µg/L) SOUTH	HAA_5 (µg/L) NORTH	HAA_5 (µg/L) EAST	HAA_5 (µg/L) WEST
Q1	6.40	5.30	5.30	8.90
Minimum	5.30	5.30	5.30	5.30
Median	13.10	8.00	10.95	12.60
Maximum	65.90	150.40	59.20	79.70
Q3	20.20	19.95	18.35	17.90
Mean	15.57	16.23	14.02	15.52
Std	10.87	17.47	10.28	9.85

Table 7.5 THM total and HAAs speciation according to water source type (using average concentrations)

	HAA_5 Total (µg/L)	THM: Total (µg/L)	TCAA (µg/L)	DCAA (µg/L)	DBAA (µg/L)	BCAA (µg/L)	MBAA (µg/L)	MCAA (µg/L)
SW Average concentration	16.62	33.87	8.16	7.11	1.67	2.08	0.85	1.07
Std	13.71	24.41	8.48	6.28	2.15	1.90	0.21	0.26
GW Average concentration	9.51	14.30	3.60	3.34	1.75	1.59	0.84	1.02
Std	9.91	15.14	6.14	4.86	1.77	1.37	0.15	0.09

Table 7.6 THM total and HAA speciation according to disinfection strategy used (using average concentrations)

	HAA5 Total (µg/L)	THM Total (µg/L)	TCAA (µg/L)	BCAA (µg/L)	DBAA (µg/L)	DCAA (µg/L)	MBAA (µg/L)	MCAA (µg/L)
Chlorinated Average concentration	16.17	31.72	8.04	2.03	1.75	6.58	0.85	1.06
Std	13.95	24.88	8.73	1.89	2.26	6.37	0.21	0.23
Chloraminated Average concentration	13.34	23.44	5.10	2.00	1.36	7.04	0.85	1.08
Std	9.84	16.80	4.96	1.65	0.68	5.33	0.15	0.27

Table 7.7 Seasonal variation of HAA5 according to disinfection strategy used

	Chloraminated				**Chlorinated**			
	AUTUMN	***WINTER***	***SPRING***	***SUMMER***	***AUTUMN***	***WINTER***	***SPRING***	***SUMMER***
Q1	6.5	5.55	5.3	6.03	8.4	5.625	5.3	6.95
Minimum	5.3	5.3	4.4	5.3	5.1	5.3	5.3	5.3
Median	11.7	7.6	8.6	11.2	13.45	10.6	10	16.2
Maximum	59.1	53.5	37.3	49.9	85.6	82.9	91.6	150.4
Q3	24.9	13.05	13.15	19.18	23.05	16.2	15.9	27.4

Table 7.8 Seasonal variation of HAA5 according to water source type

	Ground water				Surface Water			
	AUTUMN	***WINTER***	***SPRING***	***SUMMER***	***AUTUMN***	***WINTER***	***SPRING***	***SUMMER***
Q1	5.3	5.3	5.3	5.3	8.7	6.3	5.55	9.3
Minimum	5.3	5.3	5.3	5.3	5.1	5.3	4.4	5.3
Median	5.7	5.5	5.3	5.3	14.5	10.9	10.7	15.95
Maximum	53.6	53.6	34.6	74.3	85.6	82.9	91.6	150.4
Q3	14.9	6.75	6.3	6	24.1	15.95	16.1	27.25

Table 7.9 Seasonal variations of HAA species

	DCAA				TCAA				BCAA				DBAA			
	AUTUMN	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**	**WINTER**	**SPRING**	**SUMMER**	**AUTUMN**	**WINTER**	**SPRING**	**SUMMER**
Q1	2.60	2.00	1.90	2.50	2.60	1.30	1.10	1.90	0.90	1.00	0.90	0.90	1.10	1.10	1.10	1.10
LOW	1.30	1.30	1.30	1.30	1.10	1.10	1.10	1.10	0.90	0.90	0.90	0.90	1.10	1.10	1.10	1.10

Median	4.45	4.80	4.20	4.80	7.40	4.35	3.90	7.60	1.20	1.30	1.20	1.20	1.10	1.10	1.10	1.10
HIGH	35.90	46.20	36.10	65.70	62.70	43.50	54.10	82.00	20.50	22.90	8.40	11.20	15.20	21.00	15.80	34.30
Q3	10.05	7.80	7.90	10.10	13.03	7.63	7.48	12.90	2.55	2.00	2.00	2.40	1.20	1.40	1.40	1.30
Mean	7.03	5.83	6.04	7.47	9.86	5.97	6.08	9.10	2.10	1.80	1.75	1.93	1.66	1.55	1.63	1.98
Std	6.34	5.12	5.61	7.67	9.75	6.23	7.19	9.54	2.08	1.73	1.31	1.62	1.70	1.59	1.69	3.39

Table 7.10 Results tests for the two distribution zones sampling (Pateshill and Rosebery)

Sample Number	Sampled Date	Analysis	Formatted Entry	Units	Sampling location
7381743	1/7/2014 12:45	Free chlorine	0.03	MGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	THM: Total	19.7	UGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Intact cell count per ml	113100	COUNTML	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Total cell count per ml	1246000	COUNTML	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Monochloroacetic Acid	1	UGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Monobromoacetic Acid	0.8	UGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Trichloroacetic Acid	3.5	UGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Bromochloroacetic acid	0.9	UGL	PATESHILL EH52 6LN

7381743	1/7/2014 12:45	Dibromoacetic Acid	1.1	UGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	HAA5 Total	5.3	UGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Total chlorine	0.55	MGL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Hydrogen ion	8.2	PHV	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Total organic carbon	1.6	MGCL	PATESHILL EH52 6LN
7381743	1/7/2014 12:45	Dichloroacetic Acid	1.7	UGL	PATESHILL EH52 6LN
7381745	1/7/2014 15:00	Hydrogen ion	8	PHV	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Total chlorine	0.46	MGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Free chlorine	0.06	MGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Monochloroacetic Acid	1	UGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Dichloroacetic Acid	11.7	UGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Trichloroacetic Acid	7.9	UGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Bromochloroacetic acid	0.9	UGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Dibromoacetic Acid	1.1	UGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	HAA5 Total	19.6	UGL	PATESHILL EH47 8HA

7381745	1/7/2014 15:00	Total organic carbon	1.9	MGCL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	THM: Total	20	UGL	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Intact cell count per ml	660000	COUNTML	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Total cell count per ml	1872000	COUNTML	PATESHILL EH47 8HA
7381745	1/7/2014 15:00	Monobromoacetic Acid	0.8	UGL	PATESHILL EH47 8HA
7381746	1/7/2014 16:00	Hydrogen ion	8.3	PHV	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Intact cell count per ml	4180	COUNTML	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Free chlorine	0.04	MGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	THM: Total	22.1	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Total organic carbon	1.8	MGCL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Total chlorine	0.71	MGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Monochloroacetic Acid	1	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Monobromoacetic Acid	0.8	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Dichloroacetic Acid	10.5	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Trichloroacetic Acid	7	UGL	PATESHILL EH47 7AA

7381746	1/7/2014 16:00	Bromochloroacetic acid	0.9	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Dibromoacetic Acid	1.1	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	HAA5 Total	17.5	UGL	PATESHILL EH47 7AA
7381746	1/7/2014 16:00	Total cell count per ml	1334000	COUNTML	PATESHILL EH47 7AA
7381747	1/7/2014 13:15	Hydrogen ion	8	PHV	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Free chlorine	0.07	MGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Intact cell count per ml	10740	COUNTML	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Total cell count per ml	1368000	COUNTML	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Monochloroacetic Acid	1	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Monobromoacetic Acid	0.8	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Dichloroacetic Acid	10.7	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Trichloroacetic Acid	6.8	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Bromochloroacetic acid	0.9	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Dibromoacetic Acid	1.1	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	HAA5 Total	17.5	UGL	PATESHILL EH48 1EN

7381747	1/7/2014 13:15	Total organic carbon	1.8	MGCL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	THM: Total	19.8	UGL	PATESHILL EH48 1EN
7381747	1/7/2014 13:15	Total chlorine	0.61	MGL	PATESHILL EH48 1EN
7381748	1/7/2014 11:00	Hydrogen ion	8.4	PHV	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Total organic carbon	1.3	MGCL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Intact cell count per ml	42580	COUNTML	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Total cell count per ml	928000	COUNTML	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	THM: Total	28	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Monochloroacetic Acid	1	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Monobromoacetic Acid	0.8	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Dichloroacetic Acid	4.2	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Trichloroacetic Acid	5.2	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Bromochloroacetic acid	0.9	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Dibromoacetic Acid	1.1	UGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	HAA5 Total	9.4	UGL	PATESHILL EH52 6QN

7381748	1/7/2014 11:00	Total chlorine	0.45	MGL	PATESHILL EH52 6QN
7381748	1/7/2014 11:00	Free chlorine	0.18	MGL	PATESHILL EH52 6QN
7381749	1/7/2014 11:45	Free chlorine	0.06	MGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Total organic carbon	1.7	MGCL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Total chlorine	0.52	MGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	THM: Total	19.9	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Monochloroacetic Acid	1	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Monobromoacetic Acid	0.8	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Dichloroacetic Acid	11.8	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Trichloroacetic Acid	7.7	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Bromochloroacetic acid	0.9	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Dibromoacetic Acid	1.1	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	HAA5 Total	19.5	UGL	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Intact cell count per ml	3240	COUNTML	PATESHILL EH49 6NF
7381749	1/7/2014 11:45	Total cell count per ml	1124000	COUNTML	PATESHILL EH49 6NF

7381749	1/7/2014 11:45	Hydrogen ion	7.7	PHV	PATESHILL EH49 6NF
7381750	3/7/2014 16:15	Total chlorine	0.25	MGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Free chlorine	0.18	MGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Hydrogen ion	8.3	PHV	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Monochloroacetic Acid	1	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Monobromoacetic Acid	0.8	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Dichloroacetic Acid	9.1	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Trichloroacetic Acid	14.9	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Bromochloroacetic acid	1.5	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Dibromoacetic Acid	1.1	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	HAA5 Total	24	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	THM: Total	45.7	UGL	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Intact cell count per ml	10200	COUNTML	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Total cell count per ml	12780	COUNTML	ROSEBERY SOUTH EH32 9QX
7381750	3/7/2014 16:15	Total organic carbon	1.2	MGCL	ROSEBERY SOUTH EH32 9QX

7381751	3/7/2014 15:30	Total chlorine	0.04	MGL	ROSEBERY SOUTH EH34 5DU
7381751	3/7/2014 15:30	Total organic carbon	0.3	MGCL	ROSEBERY SOUTH EH34 5DU
7381751	3/7/2014 15:30	Free chlorine	0.04	MGL	ROSEBERY SOUTH EH34 5DU
7381751	3/7/2014 15:30	Hydrogen ion	7.4	PHV	ROSEBERY SOUTH EH34 5DU
7381751	3/7/2014 15:30	Intact cell count per ml	4400	COUNTML	ROSEBERY SOUTH EH34 5DU
7381751	3/7/2014 15:30	Total cell count per ml	5660	COUNTML	ROSEBERY SOUTH EH34 5DU
7381751	3/7/2014 15:30	THM: Total	3.2	UGL	ROSEBERY SOUTH EH34 5DU
7381752	3/7/2014 14:15	Monochloroacetic Acid	1	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Monobromoacetic Acid	0.8	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Dichloroacetic Acid	12.7	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Trichloroacetic Acid	12.5	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Bromochloroacetic acid	2	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Dibromoacetic Acid	1.1	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	HAA5 Total	26.2	UGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	THM: Total	46.2	UGL	ROSEBERY SOUTH EH41 4JP

7381752	3/7/2014 14:15	Total organic carbon	1.2	MGCL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Total chlorine	0.19	MGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Free chlorine	0.1	MGL	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Intact cell count per ml	14680	COUNTML	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Total cell count per ml	22720	COUNTML	ROSEBERY SOUTH EH41 4JP
7381752	3/7/2014 14:15	Hydrogen ion	7.8	PHV	ROSEBERY SOUTH EH41 4JP
7381754	3/7/2014 13:00	Intact cell count per ml	37820	COUNTML	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Total cell count per ml	44280	COUNTML	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Monochloroacetic Acid	1	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Monobromoacetic Acid	0.8	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Dichloroacetic Acid	3.8	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Trichloroacetic Acid	12.5	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Bromochloroacetic acid	0.9	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Dibromoacetic Acid	1.1	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	HAA5 Total	16.3	UGL	ROSEBERY SOUTH EH46 7BE

7381754	3/7/2014 13:00	THM: Total	48.4	UGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Hydrogen ion	9.4	PHV	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Total chlorine	0.03	MGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Free chlorine	0.03	MGL	ROSEBERY SOUTH EH46 7BE
7381754	3/7/2014 13:00	Total organic carbon	1	MGCL	ROSEBERY SOUTH EH46 7BE
7381755	3/7/2014 10:45	Monochloroacetic Acid	1	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Monobromoacetic Acid	0.8	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Dichloroacetic Acid	5.2	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Trichloroacetic Acid	8.2	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Bromochloroacetic acid	0.9	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Dibromoacetic Acid	1.1	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	HAA5 Total	13.4	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Intact cell count per ml	14380	COUNTML	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Total cell count per ml	16200	COUNTML	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Hydrogen ion	9.1	PHV	ROSEBERY SOUTH ML12 6QZ

7381755	3/7/2014 10:45	Free chlorine	0.31	MGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	THM: Total	32.5	UGL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Total organic carbon	0.9	MGCL	ROSEBERY SOUTH ML12 6QZ
7381755	3/7/2014 10:45	Total chlorine	0.36	MGL	ROSEBERY SOUTH ML12 6QZ
7381756	3/7/2014 11:30	Monochloroacetic Acid	1	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Monobromoacetic Acid	0.8	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Dichloroacetic Acid	3.9	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Trichloroacetic Acid	14.2	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Bromochloroacetic acid	0.9	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Dibromoacetic Acid	1.1	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	HAA5 Total	18.1	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	THM: Total	48.2	UGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Hydrogen ion	8.2	PHV	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Free chlorine	0.03	MGL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Total chlorine	0.13	MGL	ROSEBERY SOUTH ML12 6JD

7381756	3/7/2014 11:30	Total organic carbon	1.1	MGCL	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Intact cell count per ml	10960	COUNTML	ROSEBERY SOUTH ML12 6JD
7381756	3/7/2014 11:30	Total cell count per ml	25460	COUNTML	ROSEBERY SOUTH ML12 6JD

Table 7.11 Distribution Systems Characteristics (length, diameter, material)

PATESHILL EH52 6LN					
Type	**Diameter**	**Material**	**Legal Status**	**Asset ID**	**Length (m)**
Trunk	400mm	DI - Ductile Iron	Public	5158107	5.1
Trunk	300mm	DI - Ductile Iron	Public	5715847	2.5
Trunk	12"	CI - Cast Iron	Public	5143722	74.0
Trunk	12"	CI - Cast Iron	Public	5142688	257.0
Distribution		DI - Ductile Iron	Public	5396825	10.9
Trunk	24"	SI - Spun Iron	Public	5144551	725.3
Trunk	12"	CI - Cast Iron	Public	5158125	4.7

Trunk	15"	CI - Cast Iron	Public	5143296	7.8
Distribution		DI - Ductile Iron	Public	5142379	615.3
Trunk	18"	SI - Spun Iron	Public	5142686	408.8
Trunk	24"	SI - Spun Iron	Public	5165876	204.4
Trunk	15"	CI - Cast Iron	Public	5142656	353.2
Trunk	450mm	DI - Ductile Iron	Public	669996881	3.0
Trunk	400mm	DI - Ductile Iron	Public	5158122	3.5
Trunk	500mm	HPPE - High Performance Polyethylene	Public	669996879	935.3
Trunk	400mm	CI - Cast Iron	Public	5143882	1096.5
Trunk	300mm	DI - Ductile Iron	Public	5715849	4.3
Trunk	15"	SI - Spun Iron	Public	673859416	1214.0
Trunk	400mm	DI - Ductile Iron	Public	5158110	123.8
Trunk	12"	CI - Cast Iron	Public	5142675	1025.7
Trunk	500mm	DI - Ductile Iron	Public	670196556	9.8
Trunk	12"	CI - Cast Iron	Public	5557297	1009.5

Trunk	12"	CI - Cast Iron	Public	5142657	768.2
Trunk	12"	CI - Cast Iron	Public	5142691	5.2
Trunk	15"	CI - Cast Iron	Public	6095648	68.3
Trunk	15"	CI - Cast Iron	Public	5557032	397.7
Trunk	12"	CI - Cast Iron	Public	5557337	4371.5
Trunk	400mm	DI - Ductile Iron	Public	5158111	2.0
Distribution	250mm	DI - Ductile Iron	Public	5158108	2.8
Trunk	500mm	HPPE - High Performance Polyethylene	Public	669996855	661.0
Distribution	250mm	DI - Ductile Iron	Public	5158106	39.0
Trunk	12"	CI - Cast Iron	Public	5144023	15.0
Bypass			Public	6348407	6.7
Trunk	15"	CI - Cast Iron	Public	5143919	661.2
Trunk	12"	CI - Cast Iron	Public	5143727	25.1
Trunk	15"	CI - Cast Iron	Public	5144018	400.3
Distribution	10"	DI - Ductile Iron	Public	6095649	70.4

Trunk	18"	SI - Spun Iron	Public	5144017	450.5
Trunk	300mm	DI - Ductile Iron	Public	5158121	7.5
Trunk	12"	CI - Cast Iron	Public	5398984	1270.2
Trunk	450mm	HPPE - High Performance Polyethylene	Public	669996880	68.1
Distribution	250mm	DI - Ductile Iron	Public	5715854	2.8
Trunk	300mm	DI - Ductile Iron	Public	5158124	5.0
Trunk	15"	CI - Cast Iron	Public	5557301	234.3
Trunk	15"	CI - Cast Iron	Public	5144401	1114.4
Bypass		DI - Ductile Iron	Public	5142392	5.9
Trunk	12"	CI - Cast Iron	Public	5557305	52.4
Trunk	12"	CI - Cast Iron	Public	670336741	3.7
Trunk	24"	SI - Spun Iron	Public	5557376	241.0
Trunk	600mm	DI - Ductile Iron	Public	5165872	186.4
				Total length	19230.6

PATESHILL EH47 8HA					
Type	**Diameter**	**Material**	**Legal Status**	**Asset ID**	**Length (m)**
Distribution	8"	CI - Cast Iron	Public	5144165	8.4
Distribution	250mm	HPPE - High Performance Polyethylene	Public	665975654	43.5
Trunk	30"	CI - Cast Iron	Public	5144016	411.8
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6053837	15.3
Trunk	12"	CI - Cast Iron	Public	5557404	1187.5
Distribution	8"	CI - Cast Iron	Public	5399689	29.8
Trunk	12"	CI - Cast Iron	Public	5624145	986.9
Distribution	125mm	HPPE - High Performance Polyethylene	Public	5167569	301.3
Distribution	10"	CI - Cast Iron	Public	5144094	602.8
Distribution	8"	CI - Cast Iron	Public	5144137	89.9
Distribution	250mm	HPPE - High Performance Polyethylene	Public	5157142	308.1

Trunk	12"	DI - Ductile Iron	Public	5144557	20.4
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6053839	161.5
Trunk	12"	CI - Cast Iron	Public	5156013	6.1
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6053838	5.0
Distribution	9"	CI - Cast Iron	Public	673926414	3.9
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6204961	210.3
Distribution			Public	5768939	20.1
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6053835	15.1
Distribution	100mm	DI - Ductile Iron	Public	5144120	14.0
Trunk	12"	CI - Cast Iron	Public	5144426	21.6
Distribution	250mm	HPPE - High Performance Polyethylene	Public	5768941	3.0
Trunk	12"	CI - Cast Iron	Public	5144076	1021.1
Distribution	10"	CI - Cast Iron	Public	5144558	5.6
Trunk	12"	CI - Cast Iron	Public	5143925	185.1
Distribution	250mm	HPPE - High Performance Polyethylene	Public	666219614	437.3

Trunk	300mm	DI - Ductile Iron	Public	5557108	1290.2
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6053778	146.1
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	Public	5557040	20.2
Bypass			Public	666219613	2.0
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	Public	5144096	804.8
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	5144166	76.8
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	Public	5144106	636.2
Distribution	4"	CI - Cast Iron	Public	5716926	14.6
Distribution	9"	CI - Cast Iron	Public	5144104	19.0
Distribution	8"	CI - Cast Iron	Public	5144097	620.9
Trunk	12"	CI - Cast Iron	Public	5144427	5.7
Distribution	250mm	HPPE - High Performance Polyethylene	Public	5768935	2.7
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	Public	673924319	404.5
Distribution	250mm	MDPE - Medium Density Polyethylene	Public	6053779	101.1
Distribution	100mm		Public	6204958	2.7

Trunk	18"	SI - Spun Iron	Public	5144017	450.5
Bypass			Public	673860928	2.0
Distribution	100mm		Public	673860442	2.0
Distribution		SI - Spun Iron	Public	5157141	9.3
				Total length	10726.4

PATESHILL EH47 7AA					
Type	**Diameter**	**Material**	**Legal Status**	**Asset ID**	**Length (m)**
Trunk	15"	CI - Cast Iron	Public	5144401	1114.4
Trunk	15"	CI - Cast Iron	Public	5143919	661.2
Trunk	15"	CI - Cast Iron	Public	5144018	400.3

Distribution	10"	DI - Ductile Iron	Public	6095649	70.4
Trunk	400mm	CI - Cast Iron	Public	5143882	1096.5
Trunk	12"	CI - Cast Iron	Public	5142675	1025.7
Trunk	15"	CI - Cast Iron	Public	5142656	353.2
Trunk	15"	CI - Cast Iron	Public	6095648	68.3
Trunk	12"	CI - Cast Iron	Public	5144023	15.0
Trunk	18"	SI - Spun Iron	Public	5144017	450.5
Trunk	15"	CI - Cast Iron	Public	5557032	397.7
Trunk	12"	CI - Cast Iron	Public	5142657	768.2
				Total length	6421.3

PATESHILL EH48 1EN					
Type	**Diameter**	**Material**	**Legal Status**	**Asset ID**	**Length (m)**
Trunk	24"	SI - Spun Iron	Public	5144551	725.3
Trunk	24"	SI - Spun Iron	Public	5165876	204.4
Distribution	4"	CI - Cast Iron	Public	5143750	259.6
Trunk	15"	CI - Cast Iron	Public	5144018	400.3
Distribution	200mm	HPPE - High Performance Polyethylene	Public	5792665	3.5
Trunk	450mm	DI - Ductile Iron	Public	669996881	3.0
Distribution	9"	CI - Cast Iron	Public	5143294	42.7
Distribution	9"	CI - Cast Iron	Public	5768737	423.3
Distribution	125mm	HPPE - High Performance Polyethylene	Public	5143246	188.9
Trunk	300mm	DI - Ductile Iron	Public	5161961	10.1
Trunk	15"	CI - Cast Iron	Public	5144401	1114.4
Trunk	12"	CI - Cast Iron	Public	673859452	10.5
Trunk	12"	CI - Cast Iron	Public	5142688	257.0

Distribution	100mm	HPPE - High Performance Polyethylene	Public	5768735	2.5
Trunk	400mm	DI - Ductile Iron	Public	5158111	2.0
Trunk	12"	CI - Cast Iron	Public	5144023	15.0
Trunk	400mm	DI - Ductile Iron	Public	5158107	5.1
Trunk	15"	CI - Cast Iron	Public	5557032	397.7
Trunk	300mm	DI - Ductile Iron	Public	5158124	5.0
Distribution	5"	CI - Cast Iron	Public	6176166	60.5
Trunk	12"	CI - Cast Iron	Public	5144548	10.6
Distribution	100mm	HPPE - High Performance Polyethylene	Public	5768732	0.5
Trunk	15"	CI - Cast Iron	Public	6095648	68.3
Trunk	24"	SI - Spun Iron	Public	5557376	241.0
Trunk	500mm	DI - Ductile Iron	Public	670196556	9.8
Trunk	400mm	DI - Ductile Iron	Public	5158110	123.8
Trunk	15"	CI - Cast Iron	Public	5557301	234.3
Trunk	18"	SI - Spun Iron	Public	5142686	408.8

Trunk	12"	CI - Cast Iron	Public	5143295	421.2
Trunk	15"	CI - Cast Iron	Public	5143919	661.2
Distribution	125mm	HPPE - High Performance Polyethylene	Public	5143245	375.4
Distribution	200mm	HPPE - High Performance Polyethylene	Public	5792663	2.0
Distribution	6"	CI - Cast Iron	Public	5143682	7.3
Trunk	12"	CI - Cast Iron	Public	5161962	4.6
Trunk	500mm	HPPE - High Performance Polyethylene	Public	669996855	661.0
Distribution	250mm	DI - Ductile Iron	Public	5715854	2.8
Distribution	250mm	DI - Ductile Iron	Public	5158108	2.8
Trunk	12"	CI - Cast Iron	Public	5142675	1025.7
Distribution	4"	CI - Cast Iron	Public	5769087	13.3
Distribution	125mm	HPPE - High Performance Polyethylene	Public	6176217	19.1
Trunk	12"	CI - Cast Iron	Public	5792669	2.9
Trunk	12"	CI - Cast Iron	Public	5142691	5.2
Trunk	18"	SI - Spun Iron	Public	5144017	450.5

Distribution	10"	DI - Ductile Iron	Public	6095649	70.4
Trunk	15"	CI - Cast Iron	Public	5142656	353.2
Trunk	15"	SI - Spun Iron	Public	673859416	1214.0
Trunk	12"	CI - Cast Iron	Public	5557299	42.3
Distribution	125mm	HPPE - High Performance Polyethylene	Public	6176218	141.2
Trunk	12"	CI - Cast Iron	Public	5557062	12.5
Distribution	6"	CI - Cast Iron	Public	5398976	336.5
Trunk	15"	CI - Cast Iron	Public	5143296	7.8
Distribution	250mm	DI - Ductile Iron	Public	5158106	39.0
Trunk	500mm	HPPE - High Performance Polyethylene	Public	669996879	935.3
Trunk	12"	SI - Spun Iron	Public	5557287	1714.3
Distribution	125mm	HPPE - High Performance Polyethylene	Public	6176167	222.1
Trunk	300mm	DI - Ductile Iron	Public	5715849	4.3
Trunk	300mm	DI - Ductile Iron	Public	5158123	15.9
Distribution	100mm	HPPE - High Performance Polyethylene	Public	5768730	2.5

Trunk	600mm	DI - Ductile Iron	Public	5165872	186.4
Trunk	400mm	CI - Cast Iron	Public	5143882	1096.5
Trunk	12"	CI - Cast Iron	Public	5142657	768.2
Trunk	12"	CI - Cast Iron	Public	665975590	428.3
Trunk	450mm	HPPE - High Performance Polyethylene	Public	669996880	68.1
				Total Length	16541.4

PATESHILL EH52 6QN					
Type	**Diameter**	**Material**	**Legal Status**	**Asset ID**	**Length (m)**
Trunk	500mm	DI - Ductile Iron	Public	6.7E+08	9.8
Distribution	6"	CI - Cast Iron	Public	5718150	511.0
Distribution	6"	CI - Cast Iron	Public	5140255	144.4
Distribution	10"	CI - Cast Iron	Public	5557329	891.4
Trunk	12"	CI - Cast Iron	Public	5557305	52.4
Distribution	6"	SI - Spun Iron	Public	5140239	52.5
Trunk	12"	CI - Cast Iron	Public	5144023	15.0
Trunk	15"	CI - Cast Iron	Public	5142656	353.2
Trunk	15"	CI - Cast Iron	Public	5144018	400.3
Distribution	9"	CI - Cast Iron	Public	5142432	964.8
Trunk	15"	CI - Cast Iron	Public	5144401	1114.4
Trunk	300mm	DI - Ductile Iron	Public	5715847	2.5
Distribution	150mm	HPPE - High Performance Polyethylene	Public	5768828	1.9

Distribution	6"	CI - Cast Iron	Public	5143050	7.8
Distribution	250mm	DI - Ductile Iron	Public	5158106	39.0
Trunk	18"	SI - Spun Iron	Public	5144017	450.5
Distribution	9"	SI - Spun Iron	Public	5143411	513.8
Trunk	24"	SI - Spun Iron	Public	5144551	725.3
Trunk	12"	CI - Cast Iron	Public	5158125	4.7
Trunk	15"	CI - Cast Iron	Public	5557301	234.3
Trunk	12"	CI - Cast Iron	Public	5143727	25.1
Distribution	6"	CI - Cast Iron	Public	5140259	713.0
Distribution	10"	CI - Cast Iron	Public	5768996	1072.8
Distribution	9"	CI - Cast Iron	Public	5140385	1270.1
Trunk	500mm	HPPE - High Performance Polyethylene	Public	6.7E+08	935.3
Trunk	12"	CI - Cast Iron	Public	5142688	257.0
Distribution	250mm	DI - Ductile Iron	Public	5715854	2.8
Trunk	24"	SI - Spun Iron	Public	5165876	204.4

Trunk	400mm	DI - Ductile Iron	Public	5158122	3.5
Distribution	250mm	DI - Ductile Iron	Public	5158108	2.8
Distribution	9"	SI - Spun Iron	Public	5140217	19.6
Trunk	450mm	DI - Ductile Iron	Public	6.7E+08	3.0
Trunk	15"	SI - Spun Iron	Public	6.74E+08	1214.0
Trunk	600mm	DI - Ductile Iron	Public	5165872	186.4
Trunk	15"	CI - Cast Iron	Public	5143296	7.8
Trunk	300mm	DI - Ductile Iron	Public	5158121	7.5
Trunk	400mm	DI - Ductile Iron	Public	5158107	5.1
Trunk	400mm	DI - Ductile Iron	Public	5158111	2.0
Trunk	18"	SI - Spun Iron	Public	5142686	408.8
Trunk	12"	SI - Spun Iron	Public	5140220	509.0
Trunk	500mm	HPPE - High Performance Polyethylene	Public	6.7E+08	661.0
Distribution	150mm	HPPE - High Performance Polyethylene	Public	5768822	1.8
Trunk	15"	CI - Cast Iron	Public	6095648	68.3

Trunk	12"	CI - Cast Iron	Public	6.7E+08	3.7
Trunk	400mm	DI - Ductile Iron	Public	5158110	123.8
Trunk	12"	CI - Cast Iron	Public	5557297	1009.5
Distribution	10"	CI - Cast Iron	Public	5144317	20.5
Trunk	12"	CI - Cast Iron	Public	5398984	1270.2
Trunk	12"	CI - Cast Iron	Public	5142675	1025.7
Trunk	12"	CI - Cast Iron	Public	5143722	74.0
Distribution	6"	CI - Cast Iron	Public	5140236	5.9
Trunk	450mm	HPPE - High Performance Polyethylene	Public	6.7E+08	68.1
Distribution	6"	CI - Cast Iron	Public	5140393	2283.7
Trunk	15"	CI - Cast Iron	Public	5143919	661.2
Distribution	10"	CI - Cast Iron	Public	6.7E+08	127.0
Trunk	300mm	DI - Ductile Iron	Public	5715849	4.3
Washout			Public	5169171	4.0
Trunk	300mm	DI - Ductile Iron	Public	5158124	5.0

Trunk	12"	SI - Spun Iron	Public	5557099	25.6
Distribution	10"	CI - Cast Iron	Public	5557042	53.3
Distribution	9"	SI - Spun Iron	Public	5557104	766.6
Distribution	9"	SI - Spun Iron	Public	5140838	1070.2
Trunk	12"	CI - Cast Iron	Public	5557337	4371.5
Trunk	400mm	CI - Cast Iron	Public	5143882	1096.5
Trunk	12"	CI - Cast Iron	Public	5142657	768.2
Distribution	6"	CI - Cast Iron	Public	5140330	745.6
Distribution	9"	SI - Spun Iron	Public	5140195	1101.7
Distribution	6"	CI - Cast Iron	Public	5792796	564.1
Distribution	9"	SI - Spun Iron	Public	5768997	2.6
Distribution	10"	DI - Ductile Iron	Public	6095649	70.4
Trunk	15"	CI - Cast Iron	Public	5557032	397.7
Trunk	12"	CI - Cast Iron	Public	5142691	5.2
Trunk	24"	SI - Spun Iron	Public	5557376	241.0

Distribution	6"	CI - Cast Iron	Public	5140237	3.4
Distribution	6"	CI - Cast Iron	Public	5140331	829.1
				Total length	**32869**

PATESHILL EH49 6NF					
Type	**Diameter**	**Material**	**Legal Status**	**Asset ID**	**Length (m)**
Trunk	24"	SI - Spun Iron	Public	5144551	725.3
Trunk	12"	CI - Cast Iron	Public	5142688	257.0
Trunk	15"	CI - Cast Iron	Public	5143919	661.2
Trunk	15"	CI - Cast Iron	Public	5144018	400.3
Trunk	450mm	DI - Ductile Iron	Public	6.7E+08	3.0
Trunk	400mm	DI - Ductile Iron	Public	5158111	2.0
Distribution	6"	SI - Spun Iron	Public	5140239	52.5
Trunk	12"	CI - Cast Iron	Public	5557337	4371.5

Trunk	300mm	DI - Ductile Iron	Public	5715847	2.5
Distribution	10"	CI - Cast Iron	Public	5557329	891.4
Trunk	12"	CI - Cast Iron	Public	5144023	15.0
Trunk	18"	SI - Spun Iron	Public	5142686	408.8
Trunk	400mm	DI - Ductile Iron	Public	5158107	5.1
Trunk	300mm	DI - Ductile Iron	Public	5158124	5.0
Trunk	300mm	DI - Ductile Iron	Public	5158121	7.5
Trunk	15"	CI - Cast Iron	Public	5557301	234.3
Trunk	15"	CI - Cast Iron	Public	5144401	1114.4
Trunk	15"	CI - Cast Iron	Public	6095648	68.3
Distribution	10"	CI - Cast Iron	Public	5144317	20.5
Distribution	10"	DI - Ductile Iron	Public	6095649	70.4
Trunk	12"	CI - Cast Iron	Public	5557297	1009.5
Trunk	500mm	DI - Ductile Iron	Public	6.7E+08	9.8
Trunk	24"	SI - Spun Iron	Public	5165876	204.4

Trunk	15"	CI - Cast Iron	Public	5142656	353.2
Trunk	400mm	DI - Ductile Iron	Public	5158110	123.8
Trunk	12"	CI - Cast Iron	Public	5398984	1270.2
Trunk	12"	CI - Cast Iron	Public	5143722	74.0
Trunk	15"	CI - Cast Iron	Public	5557032	397.7
Trunk	24"	SI - Spun Iron	Public	5557376	241.0
Distribution	9"	SI - Spun Iron	Public	5557104	766.6
Distribution	9"	SI - Spun Iron	Public	5140217	19.6
Trunk	12"	CI - Cast Iron	Public	5143727	25.1
Distribution	6"	CI - Cast Iron	Public	5792796	564.1
Trunk	500mm	HPPE - High Performance Polyethylene	Public	6.7E+08	661.0
Distribution	250mm	DI - Ductile Iron	Public	5715854	2.8
Trunk	450mm	HPPE - High Performance Polyethylene	Public	6.7E+08	68.1
Distribution	250mm	DI - Ductile Iron	Public	5158108	2.8
Trunk	12"	SI - Spun Iron	Public	5557099	25.6

Distribution	6"	CI - Cast Iron	Public	5140237	3.4
Trunk	12"	CI - Cast Iron	Public	5142675	1025.7
Trunk	400mm	DI - Ductile Iron	Public	5158122	3.5
Trunk	600mm	DI - Ductile Iron	Public	5165872	186.4
Distribution	250mm	DI - Ductile Iron	Public	5158106	39.0
Trunk	400mm	CI - Cast Iron	Public	5143882	1096.5
Distribution	9"	SI - Spun Iron	Public	5140195	1101.7
Trunk	500mm	HPPE - High Performance Polyethylene	Public	6.7E+08	935.3
Distribution	10"	CI - Cast Iron	Public	6.7E+08	127.0
Washout	3"	CI - Cast Iron	Public	5140230	14.4
Trunk	12"	CI - Cast Iron	Public	6.7E+08	3.7
Trunk	12"	CI - Cast Iron	Public	5557305	52.4
Distribution	150mm	HPPE - High Performance Polyethylene	Public	5768822	1.8
Trunk	15"	SI - Spun Iron	Public	6.74E+08	1214.0
Distribution	150mm	HPPE - High Performance Polyethylene	Public	5768828	1.9

Distribution	6"	CI - Cast Iron	Public	5140236	5.9
Distribution	10"	CI - Cast Iron	Public	5557042	53.3
Distribution	10"	CI - Cast Iron	Public	5768996	1072.8
Distribution	9"	SI - Spun Iron	Public	5140838	1070.2
Trunk	15"	CI - Cast Iron	Public	5143296	7.8
Trunk	12"	SI - Spun Iron	Public	5140220	509.0
Trunk	12"	CI - Cast Iron	Public	5142691	5.2
Distribution	9"	SI - Spun Iron	Public	5143411	513.8
Trunk	18"	SI - Spun Iron	Public	5144017	450.5
Trunk	300mm	DI - Ductile Iron	Public	5715849	4.3
Trunk	12"	CI - Cast Iron	Public	5142657	768.2
Trunk	12"	CI - Cast Iron	Public	5158125	4.7
Distribution	9"	SI - Spun Iron	Public	5768997	2.6
				Total length	25410.0

ROSEBERY SOUTH EH32 9QX					
Type	**Diameter**	**Material**	**Asset ID**	**Length (m)**	**Date Commissioned**
Distribution	125mm	HPPE - High Performance Polyethylene	6092583	116.3	1/12/2007
Trunk	15"	SI - Spun Iron	6097344	10.9	1/1/1953
Distribution	150mm	DI - Ductile Iron	5168865	1.9	1/6/1988
Distribution	9"	CI - Cast Iron	6254166	54.9	1/3/1971
Trunk	600mm	DI - Ductile Iron	666205617	4160.2	1/7/2000
Trunk	450mm	DI - Ductile Iron	5979982	0.5	8/10/1997
Trunk	600mm	DI - Ductile Iron	5160845	7045.8	1/1/1999
Distribution	250mm	DI - Ductile Iron	5168854	1.9	1/6/1988
Distribution	280mm	HPPE - High Performance Polyethylene	6514279	1747.4	1/4/2007
Distribution	90mm	HPPE - High Performance Polyethylene	6092585	112.1	1/12/2007
Trunk	450mm	DI - Ductile Iron	5980002	0.5	1/7/1997
Trunk	300mm	DI - Ductile Iron	6196595	2.2	1/1/2000

Distribution	250mm	DI - Ductile Iron	5154100	1434.7	2/6/1987
Bypass	150mm	DI - Ductile Iron	5166542	7.1	25/12/1980
Distribution	250mm	DI - Ductile Iron	666243524	433.3	2/6/1987
Trunk	24"	CI - Cast Iron	5153468	1167.5	1/1/1949
Distribution	200mm	DI - Ductile Iron	6254168	1.7	1/3/2000
Trunk	300mm	DI - Ductile Iron	7472737	2.0	1/1/1999
Trunk	15"	CI - Cast Iron	6254212	43.1	1/1/1953
Bypass	9"	CI - Cast Iron	5118049	3.3	1/7/1953
Distribution	9"	CI - Cast Iron	5168820	130.5	1/1/1930
Distribution	9"	CI - Cast Iron	5147186	0.7	25/12/1900
Trunk	15"	CI - Cast Iron	5147160	1728.5	1/1/1953
Distribution	250mm	DI - Ductile Iron	5168807	13.3	1/1/1994
Distribution	250mm	DI - Ductile Iron	666220759	461.8	7/3/1998
Trunk	24"	CI - Cast Iron	5115538	1116.3	1/1/1949
Distribution	250mm	DI - Ductile Iron	5168821	9.9	1/1/1988

Trunk	450mm	DI - Ductile Iron	5979988	0.5	8/10/2004
Distribution	9"	CI - Cast Iron	5168804	8.4	1/1/1930
Trunk	24"	CI - Cast Iron	5557669	1990.5	1/1/1949
Trunk	300mm	DI - Ductile Iron	5626364	3.0	1/1/2000
Trunk	450mm	DI - Ductile Iron	5980004	350.8	1/7/1997
Trunk	450mm	DI - Ductile Iron	5979996	0.5	1/7/1997
Trunk	18"	CI - Cast Iron	5147169	2.2	1/1/1953
Distribution	280mm	HPPE - High Performance Polyethylene	666220766	223.4	1/4/2007
Trunk	15"	SI - Spun Iron	5118034	563.6	1/1/1953
Bypass	9"	CI - Cast Iron	666226555	2.8	1/7/1953
Distribution	200mm	DI - Ductile Iron	6254181	2.9	1/1/2000
Distribution	250mm	DI - Ductile Iron	5168855	1.0	1/6/1988
Distribution	9"	CI - Cast Iron	5118024	1544.0	1/1/1930
Trunk	9"	CI - Cast Iron	5557479	4.9	1/1/1958
Trunk	18"	SI - Spun Iron	5557019	1.9	1/1/1953

Trunk	9"	CI - Cast Iron	666220385	1.3	1/7/1953
Distribution	9"	CI - Cast Iron	5168808	61.1	1/1/1930
Trunk	300mm	DI - Ductile Iron	5160932	20.4	1/1/1999
Trunk	450mm	DI - Ductile Iron	5979985	469.3	8/10/1997
Distribution	9"	CI - Cast Iron	5168822	73.7	1/1/1930
Distribution	250mm	DI - Ductile Iron	666220851	187.3	1/7/1987
Trunk	15"	SI - Spun Iron	5979980	80.4	1/1/1953
Trunk	24"	CI - Cast Iron	5115963	590.2	1/1/1949
Distribution	6"	CI - Cast Iron	6253751	4.2	25/12/1900
Trunk	12"	CI - Cast Iron	5118036	7.0	1/1/1953
Bypass	150mm	DI - Ductile Iron	666243525	0.9	5/12/2013
Trunk	15"	CI - Cast Iron	5147219	150.4	1/1/1953
Trunk	400mm	DI - Ductile Iron	6254214	4.7	1/1/2000
Trunk	22"	CI - Cast Iron	5147168	2438.1	1/1/1951
Distribution	9"	CI - Cast Iron	5168817	53.9	1/1/1930

Trunk	12"	CI - Cast Iron	7472735	6.9	1/1/1950
Distribution	9"	CI - Cast Iron	5168805	20.5	1/1/1930
Trunk	15"	SI - Spun Iron	5166893	67.3	1/1/1953
Distribution	9"	CI - Cast Iron	5168806	216.4	1/1/1930
Trunk	300mm	DI - Ductile Iron	7409571	10.6	1/1/2008
Distribution	250mm	DI - Ductile Iron	5118039	21.9	25/12/1980
Distribution	180mm	HPPE - High Performance Polyethylene	666220767	36.7	1/4/2007
Distribution	180mm	POLY - Polyethylene	5168812	3.0	1/1/1994
Trunk	15"	SI - Spun Iron	5979995	715.9	1/1/1953
Trunk	15"	CI - Cast Iron	5118035	1.5	1/1/1953
Bypass	150mm	DI - Ductile Iron	666243529	1.6	5/12/2013
Distribution	150mm	DI - Ductile Iron	5168809	2.8	1/1/1994
Trunk	24"	CI - Cast Iron	5115991	269.6	1/1/1949
Bypass	150mm	DI - Ductile Iron	6095108	3.6	25/12/1985
Distribution	150mm	DI - Ductile Iron	5154116	3.7	1/1/1987

Distribution	250mm	DI - Ductile Iron	5168810	6.9	1/1/1994
Trunk	18"	SI - Spun Iron	5118037	39.7	1/1/1953
Distribution	9"	CI - Cast Iron	673859251	3.8	25/12/1910
Distribution	9"	CI - Cast Iron	5118038	21.9	1/1/1953
Trunk	15"	SI - Spun Iron	666220392	219.7	1/7/1953
Distribution	150mm	DI - Ductile Iron	5559027	1.0	1/6/1988
Trunk	27"	CI - Cast Iron	7409570	490.5	1/1/1949
Distribution	150mm	DI - Ductile Iron	5168813	3.0	1/1/1994
Trunk	15"	CI - Cast Iron	5557477	43.2	1/1/1953
Trunk	9"	CI - Cast Iron	666220399	0.5	1/7/1953
Trunk	15"	SI - Spun Iron	5557238	569.6	1/7/1953
Distribution	225mm	HPPE - High Performance Polyethylene	6092581	423.6	1/4/2007
Trunk	24"	CI - Cast Iron	5147077	1467.7	1/1/1949
Distribution	250mm	DI - Ductile Iron	5168816	10.0	1/1/1988
Distribution	9"	CI - Cast Iron	6097343	2.4	25/12/1910

Trunk	15"	SI - Spun Iron	5147180	205.0	1/1/1953
			Total length	33542.7	

ROSEBERY SOUTH EH41 4JP					
Type	**Diameter**	**Material**	**Date Commissioned**	**Asset ID**	**Length (m)**
Distribution	100mm	DI - Ductile Iron	1/6/1993	6187390	16.8
Trunk	600mm	DI - Ductile Iron	1/1/1999	5160845	7045.8
Distribution	180mm	HPPE - High Performance Polyethylene	1/1/2001	5165150	3.9
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2002	6050974	722.6
Distribution	100mm	DI - Ductile Iron	1/6/2001	666226236	0.8
Trunk	12"	CI - Cast Iron	1/1/1950	7472735	6.9
Trunk	300mm	DI - Ductile Iron	1/1/1999	7472737	2.0
Distribution	180mm	HPPE - High Performance Polyethylene	1/1/2001	5165148	9257.9
Distribution	250mm	HPPE - High Performance Polyethylene	1/7/2000	5160478	125.3

Distribution	4"	AC - Asbestos Cement	1/6/1957	5145350	1082.9
Distribution	150mm	DI - Ductile Iron	1/1/2001	5165352	14.9
Trunk	24"	CI - Cast Iron	1/1/1949	5115991	269.6
Distribution	100mm	DI - Ductile Iron	1/6/2001	5717761	2.1
Distribution	150mm	DI - Ductile Iron	1/1/2001	5165361	905.6
Distribution	125mm	MDPE - Medium Density Polyethylene	1/1/2001	5979432	954.2
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2000	666215153	0.5
Distribution	125mm	MDPE - Medium Density Polyethylene	1/1/1997	5165163	842.9
Distribution	125mm	MDPE - Medium Density Polyethylene	1/1/1997	5147349	23.9
Distribution	110mm	MOPVC	1/6/1993	6187391	78.4
Trunk	24"	CI - Cast Iron	1/1/1949	5557669	1990.5
Trunk	24"	CI - Cast Iron	1/1/1949	5115538	1116.3
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2001	5162706	534.7
Trunk	24"	CI - Cast Iron	1/1/1949	5153468	1167.5
Distribution	125mm	POLY - Polyethylene	1/1/2003	5717673	6.9

Distribution	125mm	MDPE - Medium Density Polyethylene	1/1/1997	5165362	5.1
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2003	5717668	32.5
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2004	6050973	388.5
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2004	6050972	353.0
Distribution	4"	PVC - Polyvinyl Chloride	18/3/1986	5164726	170.5
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2004	6050949	51.1
Distribution	100mm	DI - Ductile Iron	18/3/1986	5164730	113.5
Distribution	110mm	MOPVC	1/6/1993	5145353	107.5
Distribution	150mm	DI - Ductile Iron	1/1/2001	6096012	9.5
Trunk	300mm	DI - Ductile Iron	1/1/2000	6196595	2.2
Distribution	4"	PVC - Polyvinyl Chloride	18/3/1986	5164744	188.5
Distribution	4"	PVC - Polyvinyl Chloride	18/3/1986	5164725	481.9
Distribution	100mm	DI - Ductile Iron	18/3/1986	5164729	22.9
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2000	5165428	0.5
Distribution	150mm	DI - Ductile Iron	1/1/2001	6096013	40.7

Trunk	24"	CI - Cast Iron	1/1/1949	5147077	1467.7
Distribution	4"	PVC - Polyvinyl Chloride	18/3/1986	5164743	296.4
Trunk	300mm	DI - Ductile Iron	1/1/1999	5160932	20.4
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2003	5168851	846.9
Distribution	4"	AC - Asbestos Cement	25/12/1960	6514048	1988.6
Trunk	300mm	DI - Ductile Iron	1/1/2000	5626364	3.0
Distribution	250mm	HPPE - High Performance Polyethylene	1/1/2000	5165427	11.5
Distribution	125mm	HDPE - High Density Polyethylene	1/1/2001	5162707	629.5
Distribution	125mm	POLY - Polyethylene	1/1/2004	5168852	23.4
Trunk	300mm	DI - Ductile Iron	1/1/2008	7409571	10.6
Bypass	80mm	DI - Ductile Iron	1/6/2001	5717762	1.4
Distribution	100mm	DI - Ductile Iron	1/6/1980	5717793	3.6
Trunk	24"	CI - Cast Iron	1/1/1949	5115963	590.2
Trunk	600mm	DI - Ductile Iron	1/7/2000	666205617	4160.2
Distribution	100mm	DI - Ductile Iron	1/6/1980	665974320	1.2

Distribution	100mm	DI - Ductile Iron	25/12/1985	5146555	48.9
Trunk	27"	CI - Cast Iron	1/1/1949	7409570	490.5
Distribution	100mm	DI - Ductile Iron	18/3/1986	5164748	16.9
Distribution	180mm	HPPE - High Performance Polyethylene	1/1/2001	5961962	4.9
Distribution	250mm	HPPE - High Performance Polyethylene	1/1/2000	5421580	0.3
Distribution	100mm	DI - Ductile Iron	18/3/1986	5164727	6.3
Distribution	125mm	HPPE - High Performance Polyethylene	1/1/2003	5717671	2441.1
Bypass	80mm	DI - Ductile Iron	1/6/2001	673859857	2.0
				Total length	41206.3

ROSEBERY SOUTH EH46 7BE					
Type	**Diameter**	**Material**	**Date Commissioned**	**Asset ID**	**Length (m)**
Bypass	200mm	DI - Ductile Iron	2/8/2004	6093309	4.3

Trunk	600mm	DI - Ductile Iron	1/1/1983	5115059	795.9
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186231	3.2
Trunk	400mm	DI - Ductile Iron	25/12/1980	5114953	101.4
Distribution	200mm	DI - Ductile Iron	1/9/1991	5154853	1323.1
Trunk	400mm	POLY - Polyethylene	1/1/2007	6159547	48.4
Distribution	3"	CI - Cast Iron	1/1/1970	5159605	4.0
Trunk	300mm	DI - Ductile Iron	2/8/2004	6347423	1837.3
Bypass	150mm	DI - Ductile Iron	2/8/2004	6093271	2.5
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	6077401	3.1
Distribution	4"	AC - Asbestos Cement	1/1/1950	5168659	1615.1
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114565	674.8
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719770	237.3
Trunk	300mm	DI - Ductile Iron	2/8/2004	2837535	1278.1
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719705	490.1
Trunk	300mm	DI - Ductile Iron	2/8/2004	6093269	25.3

Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719795	1153.1
Trunk	16"	CI - Cast Iron	1/1/1953	666204954	22.5
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114638	953.3
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	5154859	1014.9
Distribution	200mm	DI - Ductile Iron	1/9/1991	5154857	965.7
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347374	0.4
Trunk	16"	CI - Cast Iron	1/1/1953	5146825	1720.1
Distribution	200mm	DI - Ductile Iron	1/9/2005	666224074	7.2
Distribution	150mm	DI - Ductile Iron	29/8/2005	6076444	1.2
Trunk	400mm	DI - Ductile Iron	1/1/1985	5114567	237.2
Trunk	400mm	DI - Ductile Iron	1/7/1984	5114526	1326.7
Distribution	200mm	DI - Ductile Iron	1/9/1991	5159446	10.2
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114557	1314.5
Bypass	200mm	DI - Ductile Iron	2/8/2004	6149397	4.5
Distribution	200mm	DI - Ductile Iron	1/1/1994	6096006	4372.9

Trunk	200mm	DI - Ductile Iron	1/1/1984	6347376	15.9
Distribution	4"	CI - Cast Iron	1/1/1970	5159604	155.9
Trunk	16"	CI - Cast Iron	01/01/1890	5153466	980.8
Distribution	4"	uPVC - Unplasticised Poly Vinyl Chloride	1/1/1969	5168658	252.7
Distribution	100mm	DI - Ductile Iron	1/1/1979	5159561	6.1
Distribution	150mm	DI - Ductile Iron	29/8/2005	6076434	1.4
Trunk	27"	CI - Cast Iron	1/1/1949	7409570	490.5
Distribution	200mm	DI - Ductile Iron	1/8/2004	6149400	115.0
Distribution	200mm	DI - Ductile Iron	1/8/2004	6077388	1.3
Distribution	100mm	DI - Ductile Iron	1/1/1980	6078435	282.1
Distribution	4"	AC - Asbestos Cement	1/1/1950	5159581	870.4
Distribution	100mm	DI - Ductile Iron	1/1/1979	6077386	3.6
Trunk	300mm	DI - Ductile Iron	2/8/2004	2837538	20.2
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347375	81.5
Trunk	16"	CI - Cast Iron	01/01/1890	5115223	669.7

Trunk	500mm	DI - Ductile Iron	1/1/1985	5114954	694.1
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186229	7.8
Bypass	300mm	DI - Ductile Iron	1/1/2004	6347331	5.0
Trunk	16"	CI - Cast Iron	01/01/1890	666243584	1264.0
Trunk	600mm	DI - Ductile Iron	1/1/2007	6514236	0.6
Distribution	80mm	DI - Ductile Iron	1/1/1980	5628783	361.3
Distribution	80mm	DI - Ductile Iron	1/1/1980	5159562	280.5
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719706	49.0
Trunk	600mm	DI - Ductile Iron	1/1/1983	5115218	576.4
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114452	454.1
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347356	84.6
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719836	545.6
Distribution	4"	AC - Asbestos Cement	1/4/1970	5159575	713.0
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114952	580.1
Distribution	4"	AC - Asbestos Cement	1/1/1950	5719862	195.8

Bypass	400mm	DI - Ductile Iron	1/1/2004	6186188	1.4
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186230	2.1
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347346	11.8
Distribution	200mm	DI - Ductile Iron	1/1/1994	6096008	75.1
Trunk	400mm	DI - Ductile Iron	1/7/1984	666226129	152.5
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721244	5.9
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347323	1.4
Distribution	150mm	DI - Ductile Iron	1/8/2004	6149399	3.0
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719771	404.9
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114564	358.6
Trunk	16"	CI - Cast Iron	01/01/1890	5115216	600.1
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347350	3.7
Bypass	150mm	DI - Ductile Iron	2/8/2004	6186147	2.4
Distribution	100mm	DI - Ductile Iron	1/1/1980	5159565	357.4
Distribution	100mm	DI - Ductile Iron	1/1/1979	5159560	1.7

Distribution	200mm	DI - Ductile Iron	1/9/2005	6093263	16.4
Distribution	150mm	DI - Ductile Iron	29/8/2005	673860179	0.7
Distribution	150mm	DI - Ductile Iron	1/8/2004	5721247	3.0
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	6076433	1.5
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347325	3.0
Distribution	150mm	DI - Ductile Iron	1/9/2005	6186237	1.6
Trunk	250mm	DI - Ductile Iron	1/1/2007	6514221	9.2
Distribution	4"	AC - Asbestos Cement	1/1/1950	5159582	202.2
Distribution	180mm	HPPE - High Performance Polyethylene	15/3/2005	6077367	3003.1
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721251	0.7
Distribution	4"	AC - Asbestos Cement	1/1/1950	5162740	1169.1
Bypass	400mm	DI - Ductile Iron	1/1/2004	6186187	1.3
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114479	436.3
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	5154861	1572.3
Bypass	300mm	DI - Ductile Iron	1/1/2004	6347341	4.4

Distribution	100mm	DI - Ductile Iron	1/1/1980	5159564	2.9
Trunk	200mm	DI - Ductile Iron	1/1/1984	6347384	3.1
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719680	839.8
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721238	137.7
Distribution	200mm	DI - Ductile Iron	1/9/2005	6149398	34.7
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	1/1/1979	5115219	1.1
Trunk	16"	CI - Cast Iron	01/01/1890	5958579	74.9
Distribution	4"	CI - Cast Iron	1/1/1970	5159578	128.4
Distribution	5"	AC - Asbestos Cement	1/12/1970	5159576	223.4
Distribution	4"	AC - Asbestos Cement	1/1/1950	5159574	933.0
				Total length	42093.3

		ROSEBERY SOUTH ML12 6QZ			
Type	Diameter	Material	Date Commissioned	Asset ID	Length (m)
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114952	580.1
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114564	358.6
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347346	11.8
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721244	5.9
Bypass	400mm	DI - Ductile Iron	1/1/2004	6186187	1.3
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186231	3.2
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114954	694.1
Distribution	200mm	DI - Ductile Iron	1/8/2004	6077388	1.3
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114565	674.8
Bypass	400mm	DI - Ductile Iron	1/1/2004	6186188	1.4
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114479	436.3
Distribution	200mm	DI - Ductile Iron	1/9/1991	5154853	1323.1
Distribution	90mm	HDPE - High Density Polyethylene	1/1/1996	666207513	1.2

Bypass	200mm	DI - Ductile Iron	2/8/2004	6149397	4.5
Trunk	400mm	DI - Ductile Iron	25/12/1980	5114953	101.4
Distribution	90mm	HDPE - High Density Polyethylene	1/1/1996	5155123	946.3
Distribution	200mm	DI - Ductile Iron	1/9/2005	6149398	34.7
Trunk	16"	CI - Cast Iron	01/01/1890	5153466	980.8
Distribution	150mm	DI - Ductile Iron	1/8/2004	6149399	3.0
Bypass	150mm	DI - Ductile Iron	2/8/2004	6186147	2.4
Trunk	16"	CI - Cast Iron	1/1/1953	666204954	22.5
Trunk	16"	CI - Cast Iron	01/01/1890	5958579	74.9
Distribution	90mm	HDPE - High Density Polyethylene	1/1/1996	5155124	1045.6
Bypass	200mm	DI - Ductile Iron	2/8/2004	6093309	4.3
Distribution	200mm	DI - Ductile Iron	1/8/2004	6149400	115.0
Distribution	4"	AC - Asbestos Cement	1/1/1966	1422232	399.8
Trunk	200mm	DI - Ductile Iron	1/1/1984	6347376	15.9
Distribution	4"	AC - Asbestos Cement	1/1/1966	1422233	24.3

Trunk	16"	CI - Cast Iron	01/01/1890	666243584	1264.0
Trunk	600mm	DI - Ductile Iron	1/1/1983	5115059	795.9
Distribution	90mm	HPPE - High Performance Polyethylene	1/2/2004	2010222	523.6
Bypass	300mm	DI - Ductile Iron	1/1/2004	6347331	5.0
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347350	3.7
Distribution	90mm	HPPE - High Performance Polyethylene	1/2/2004	2010225	988.7
Distribution	4"	CI - Cast Iron	1/1/1966	1422237	14.4
Bypass				673860182	1.5
Distribution	180mm	HPPE - High Performance Polyethylene	15/3/2005	6077410	3.0
Trunk	300mm	DI - Ductile Iron	2/8/2004	2837538	20.2
Distribution	4"	CI - Cast Iron	1/1/1966	1422231	52.4
Trunk	300mm	DI - Ductile Iron	2/8/2004	2837535	1278.1
Distribution	180mm	HPPE - High Performance Polyethylene	15/3/2005	6077367	3003.1
Trunk	400mm	POLY - Polyethylene	1/1/2007	6159547	48.4
Distribution	200mm	DI - Ductile Iron	1/9/2005	666224074	7.2

Distribution	4"	CI - Cast Iron	1/1/1966	2010256	10.7
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721251	0.7
Trunk	400mm	DI - Ductile Iron	1/7/1984	666226129	152.5
Trunk	16"	CI - Cast Iron	01/01/1890	5115216	600.1
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	5154861	1572.3
Trunk	600mm	DI - Ductile Iron	1/1/1983	5115218	576.4
Distribution	90mm	HPPE - High Performance Polyethylene	1/11/2003	6079746	10.3
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	6077401	3.1
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347356	84.6
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	1/1/1979	5115219	1.1
Trunk	250mm	DI - Ductile Iron	1/1/2007	6514221	9.2
Trunk	27"	CI - Cast Iron	1/1/1949	7409570	490.5
Distribution	90mm	HPPE - High Performance Polyethylene	1/2/2004	2010179	1260.2
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114452	454.1
Trunk	300mm	DI - Ductile Iron	2/8/2004	6347423	1837.3

Trunk	400mm	DI - Ductile Iron	1/7/1984	5114526	1326.7
Distribution	200mm	DI - Ductile Iron	1/9/1991	5154857	965.7
Trunk	600mm	DI - Ductile Iron	1/1/2007	6514236	0.6
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347374	0.4
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114557	1314.5
Bypass	300mm	DI - Ductile Iron	1/1/2004	6347341	4.4
Distribution	90mm	HDPE - High Density Polyethylene	1/1/1996	5155122	733.0
Bypass				6149413	0.5
Distribution	180mm	HPPE - High Performance Polyethylene	15/3/2005	6077411	2.0
Distribution	180mm	HPPE - High Performance Polyethylene	15/3/2005	6190875	8.0
Distribution	200mm	DI - Ductile Iron	1/1/1994	6096008	75.1
Distribution	150mm	DI - Ductile Iron	1/9/2005	6186237	1.6
Trunk	300mm	DI - Ductile Iron	2/8/2004	6093269	25.3
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	5154859	1014.9
Trunk	400mm	DI - Ductile Iron	1/1/1985	5114567	237.2

Distribution	4"	CI - Cast Iron	1/1/1966	1422235	36.6
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347325	3.0
Distribution	4"	AC - Asbestos Cement	1/1/1966	1422236	119.6
Distribution	4"	AC - Asbestos Cement	1/1/1966	464810	252.3
Distribution	150mm	DI - Ductile Iron	1/8/2004	5721247	3.0
Distribution	200mm	DI - Ductile Iron	1/1/1994	6096006	4372.9
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721238	137.7
Distribution	200mm	DI - Ductile Iron	1/9/1991	5159446	10.2
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347323	1.4
Trunk	16"	CI - Cast Iron	1/1/1953	5146825	1720.1
Trunk	16"	CI - Cast Iron	01/01/1890	5115223	669.7
Distribution	4"	AC - Asbestos Cement	1/1/1966	673857920	541.1
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347375	81.5
Distribution	90mm	HDPE - High Density Polyethylene	1/1/1996	673860177	1944.7
Trunk	200mm	DI - Ductile Iron	1/1/1984	6347384	3.1

Distribution	200mm	DI - Ductile Iron	2/8/2004	6186229	7.8
Distribution	200mm	DI - Ductile Iron	1/9/2005	6093263	16.4
Distribution	90mm	HPPE - High Performance Polyethylene	1/11/2003	6190877	1.2
Distribution	4"	AC - Asbestos Cement	1/1/1966	464793	775.4
Distribution	4"	AC - Asbestos Cement	1/1/1966	488150	283.1
Bypass				6751244	3.0
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114638	953.3
Distribution	4"	AC - Asbestos Cement	1/1/1966	464794	318.9
Bypass	150mm	DI - Ductile Iron	2/8/2004	6093271	2.5
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186230	2.1
				Total length	40911.5

ROSEBERY SOUTH ML12 6JD					
Type	**Diameter**	**Material**	**Date Commissioned**	**Asset ID**	**Length (m)**
Trunk	300mm	DI - Ductile Iron	2/8/2004	2837535	1278.1
Trunk	16"	CI - Cast Iron	01/01/1890	5115223	669.7
Distribution	110mm	HPPE - High Performance Polyethylene	1/5/2004	665976358	8009.0
Distribution	110mm	HPPE - High Performance Polyethylene	1/5/2004	5720967	196.0
Bypass	400mm	DI - Ductile Iron	1/1/2004	6186187	1.3
Trunk	200mm	DI - Ductile Iron	1/1/1984	6347376	15.9
Bypass	200mm	DI - Ductile Iron	2/8/2004	6149397	4.5
Distribution	150mm	DI - Ductile Iron	1/8/2004	6149399	3.0
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719795	1153.1
Bypass	150mm	DI - Ductile Iron	2/8/2004	6186147	2.4

Trunk	400mm	DI - Ductile Iron	25/12/1980	5114953	101.4
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721251	0.7
Distribution	150mm	DI - Ductile Iron	1/1/1985	5720987	1305.9
Distribution	200mm	DI - Ductile Iron	1/9/1991	5154857	965.7
Distribution	125mm	HDPE - High Density Polyethylene	1/11/1994	670663544	780.6
Trunk	16"	CI - Cast Iron	01/01/1890	5958579	74.9
Distribution	150mm	DI - Ductile Iron	1/9/2005	6186237	1.6
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719771	404.9
Distribution	180mm	HPPE - High Performance Polyethylene	15/3/2005	6077367	3003.1
Distribution	2"	AC - Asbestos Cement	25/12/1950	670663555	161.6
Trunk	200mm	DI - Ductile Iron	1/1/1984	6347384	3.1
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347375	81.5
Distribution	200mm	DI - Ductile Iron	1/9/1991	5159446	10.2
Trunk	16"	CI - Cast Iron	1/1/1953	5146825	1720.1

Distribution	200mm	DI - Ductile Iron	1/9/2005	6149398	34.7
Bypass	300mm	DI - Ductile Iron	1/1/2004	6347341	4.4
Distribution	125mm	HPPE - High Performance Polyethylene	1/5/2004	5720977	1412.8
Distribution	200mm	DI - Ductile Iron	1/8/2004	6077388	1.3
Distribution	90mm	HPPE - High Performance Polyethylene	1/5/2004	6190874	2.3
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347350	3.7
Bypass	200mm	DI - Ductile Iron	2/8/2004	6093309	4.3
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114479	436.3
Distribution	125mm	HPPE - High Performance Polyethylene	1/2/2004	6190873	32.3
Distribution	200mm	DI - Ductile Iron	1/9/2005	666224074	7.2
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721244	5.9
Distribution	160mm	HPPE - High Performance Polyethylene	1/5/2004	5721046	2046.7
Distribution	90mm	HPPE - High Performance Polyethylene	1/5/2004	673859867	2.0

Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719680	839.8
Distribution	90mm	HPPE - High Performance Polyethylene	1/5/2004	5720969	2.0
Distribution	110mm	HPPE - High Performance Polyethylene	1/5/2004	5720903	3.5
Distribution	160mm	HPPE - High Performance Polyethylene	1/5/2004	5721130	864.8
Trunk	300mm	DI - Ductile Iron	2/8/2004	6347423	1837.3
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114564	358.6
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114954	694.1
Trunk	400mm	DI - Ductile Iron	1/7/1984	5114526	1326.7
Trunk	600mm	DI - Ductile Iron	1/1/1983	5115218	576.4
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719705	490.1
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186231	3.2
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347325	3.0
Trunk	16"	CI - Cast Iron	01/01/1890	5153466	980.8

Trunk	500mm	DI - Ductile Iron	1/1/1985	5114952	580.1
Distribution	100mm	DI - Ductile Iron	1/8/1980	5148972	1730.5
Distribution	200mm	DI - Ductile Iron	1/1/1994	6096006	4372.9
Distribution	80mm	HPPE - High Performance Polyethylene		6751155	4.5
Trunk	400mm	POLY - Polyethylene	1/1/2007	6159547	48.4
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114565	674.8
Distribution	180mm	HDPE - High Density Polyethylene	1/1/1999	5159999	609.8
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114452	454.1
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347374	0.4
Bypass	400mm	DI - Ductile Iron	1/1/2004	6186188	1.4
Bypass	150mm	DI - Ductile Iron	2/8/2004	6093271	2.5
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186229	7.8
Distribution	160mm	HPPE - High Performance Polyethylene	1/5/2004	5721152	269.0
Trunk	16"	CI - Cast Iron	01/01/1890	666243584	1264.0

Bypass	125mm	HPPE - High Performance Polyethylene	1/2/2004	6190872	3.5
Distribution	200mm	DI - Ductile Iron	1/8/2004	6149400	115.0
Distribution	125mm	HPPE - High Performance Polyethylene	1/2/2004	5721149	140.0
Distribution	200mm	DI - Ductile Iron	1/9/1991	5154853	1323.1
Trunk	16"	CI - Cast Iron	1/1/1953	666204954	22.5
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	5154861	1572.3
Trunk	600mm	DI - Ductile Iron	1/1/1983	5115059	795.9
Trunk	400mm	DI - Ductile Iron	1/7/1984	666226129	152.5
Trunk	400mm	DI - Ductile Iron	1/1/1985	5114567	237.2
Trunk	250mm	DI - Ductile Iron	1/1/2007	6514221	9.2
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719770	237.3
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	6077401	3.1
Distribution	180mm	HPPE - High Performance Polyethylene	1/2/2004	5719706	49.0

Bypass	300mm	DI - Ductile Iron	1/1/2004	6347331	5.0
Trunk	300mm	DI - Ductile Iron	1/1/1984	6347346	11.8
Bypass	125mm	HPPE - High Performance Polyethylene	1/2/2004	5719878	3.5
Trunk	500mm	DI - Ductile Iron	1/1/1985	5114557	1314.5
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347356	84.6
Trunk	600mm	DI - Ductile Iron	1/1/2007	6514236	0.6
Distribution	90mm	HPPE - High Performance Polyethylene	28/1/2009	670663526	2385.8
Distribution	100mm	DI - Ductile Iron	1/9/1980	5148938	47.4
Trunk	400mm	DI - Ductile Iron	1/1/1984	5114638	953.3
Distribution	160mm	HPPE - High Performance Polyethylene	1/5/2004	5721027	1048.9
Distribution	80mm	HPPE - High Performance Polyethylene		673860712	4.5
Distribution	150mm	DI - Ductile Iron	1/8/2004	5721247	3.0
Distribution	200mm	PVC - Polyvinyl Chloride	1/10/1991	5154859	1014.9

Trunk	300mm	DI - Ductile Iron	2/8/2004	2837538	20.2
Trunk	16"	CI - Cast Iron	01/01/1890	5115216	600.1
Distribution	200mm	DI - Ductile Iron	1/8/2004	5721238	137.7
Trunk	300mm	DI - Ductile Iron	2/8/2004	6093269	25.3
Distribution	160mm	HPPE - High Performance Polyethylene	1/5/2004	5721045	60.9
Distribution	200mm	DI - Ductile Iron	1/1/1994	6096008	75.1
Distribution	200mm	DI - Ductile Iron	1/9/2005	6093263	16.4
Trunk	12"	uPVC - Unplasticised Poly Vinyl Chloride	1/1/1979	5115219	1.1
Trunk	400mm	DI - Ductile Iron	1/1/1984	6347323	1.4
Trunk	27"	CI - Cast Iron	1/1/1949	7409570	490.5
Distribution	200mm	DI - Ductile Iron	2/8/2004	6186230	2.1
				Total length	54912.1

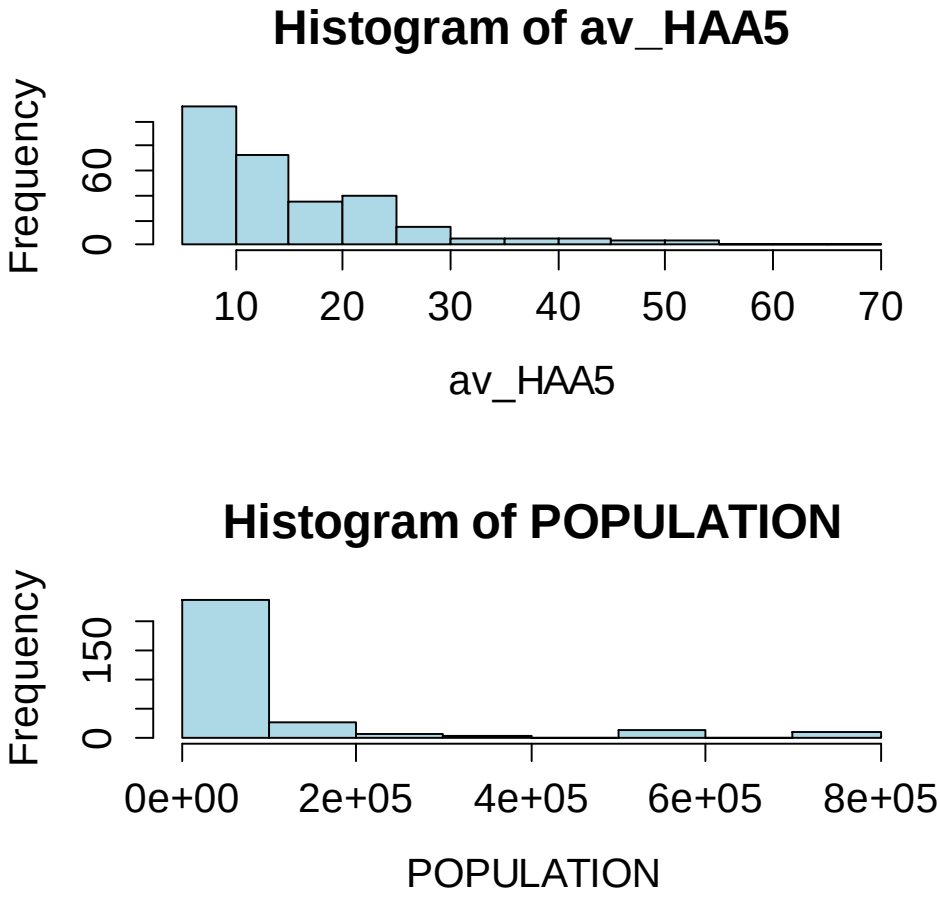

Figure 7.1 Histogram of annual average HAA5 concentration (µg/L) and of Population served

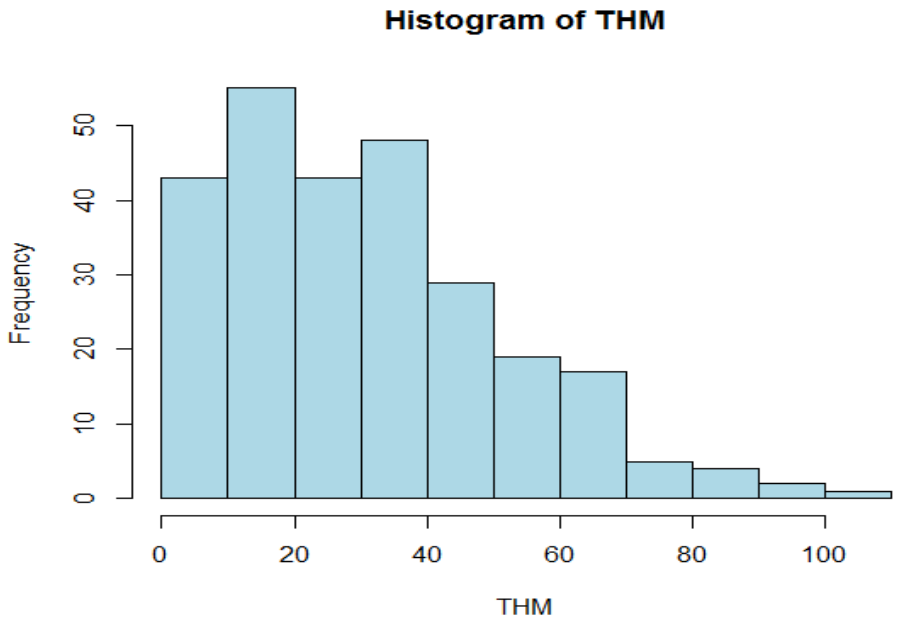

Figure 7.2 Histogram of annual average THMs total concentration (µg/L).

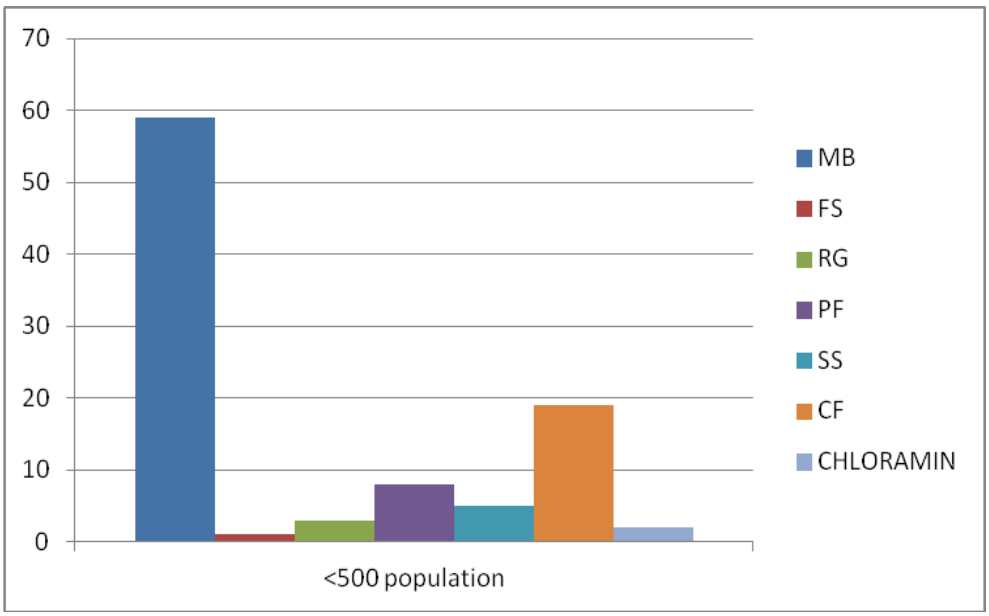

Figure 7.3 WTW serving <500 people treatment stages

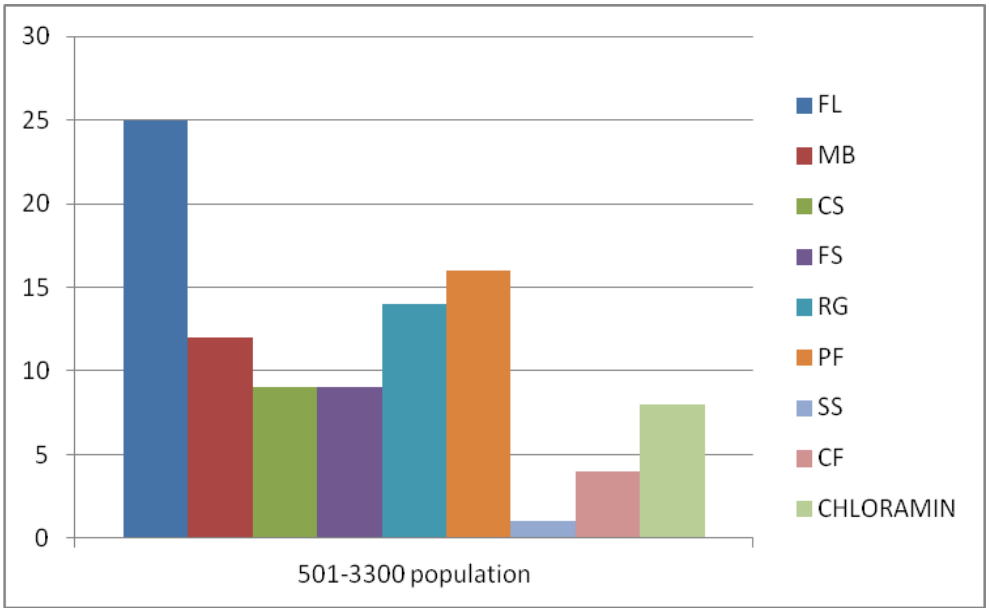

Figure 7.4 WTW serving 501-3300 people treatment stages

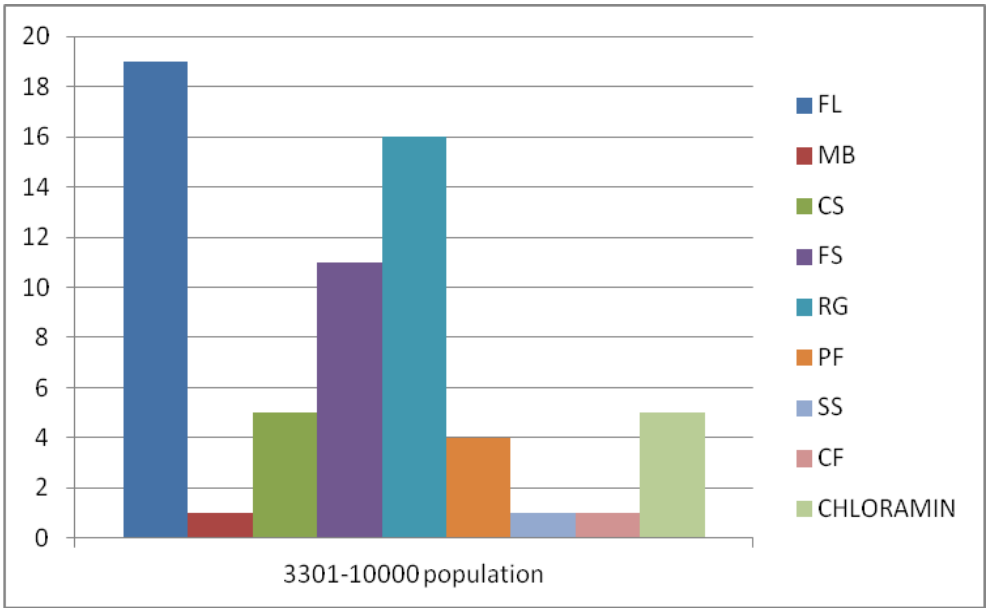

Figure 7.5 WTW serving 3301-10000 people treatment stages

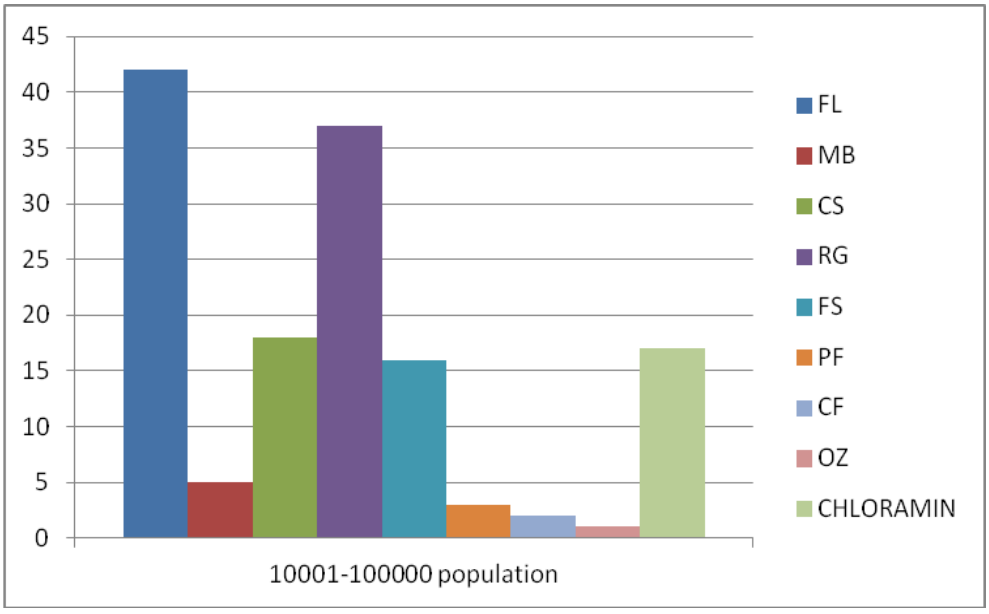

Figure 7.6 WTW serving 10001-100000 inhabitants treatment stages

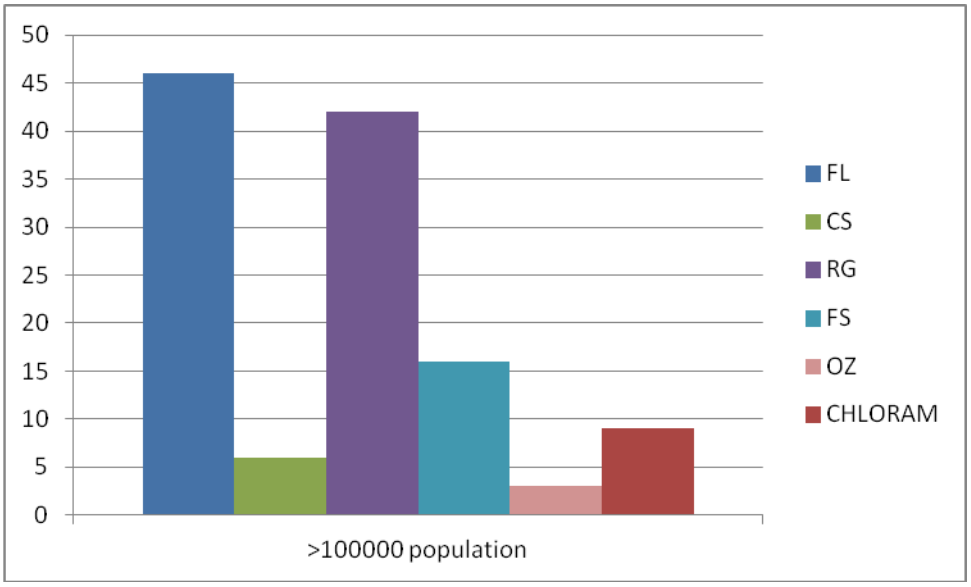

Figure 7.7 WTW serving >100000 people treatment stages

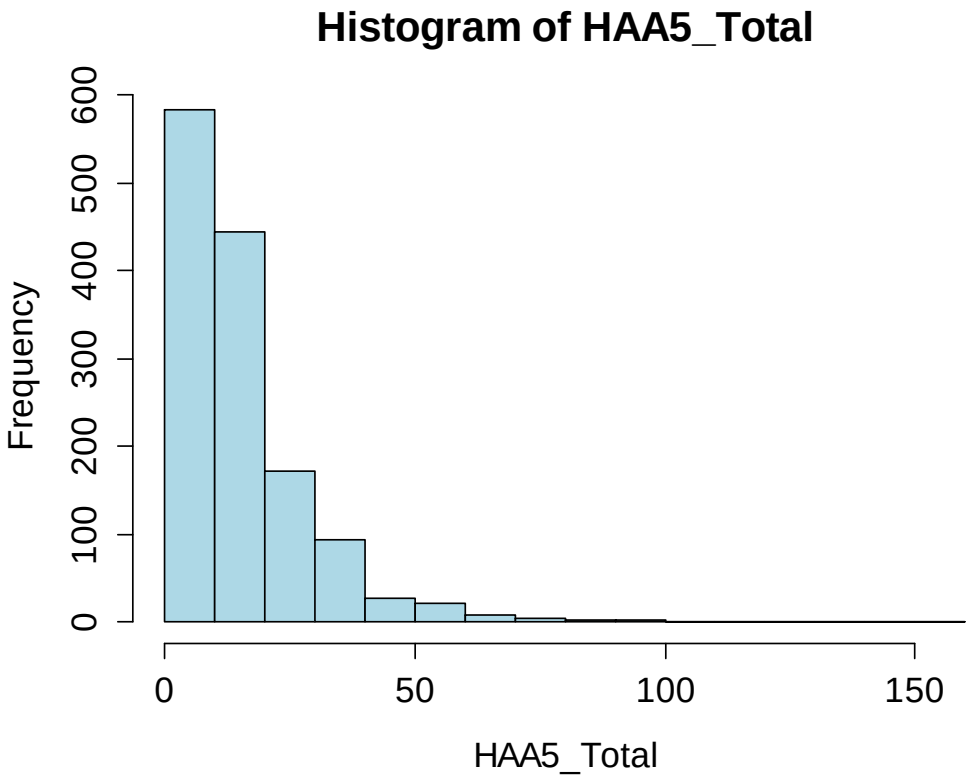

Figure 7.8 Histogram of HAA5 total concentration (µg/L).

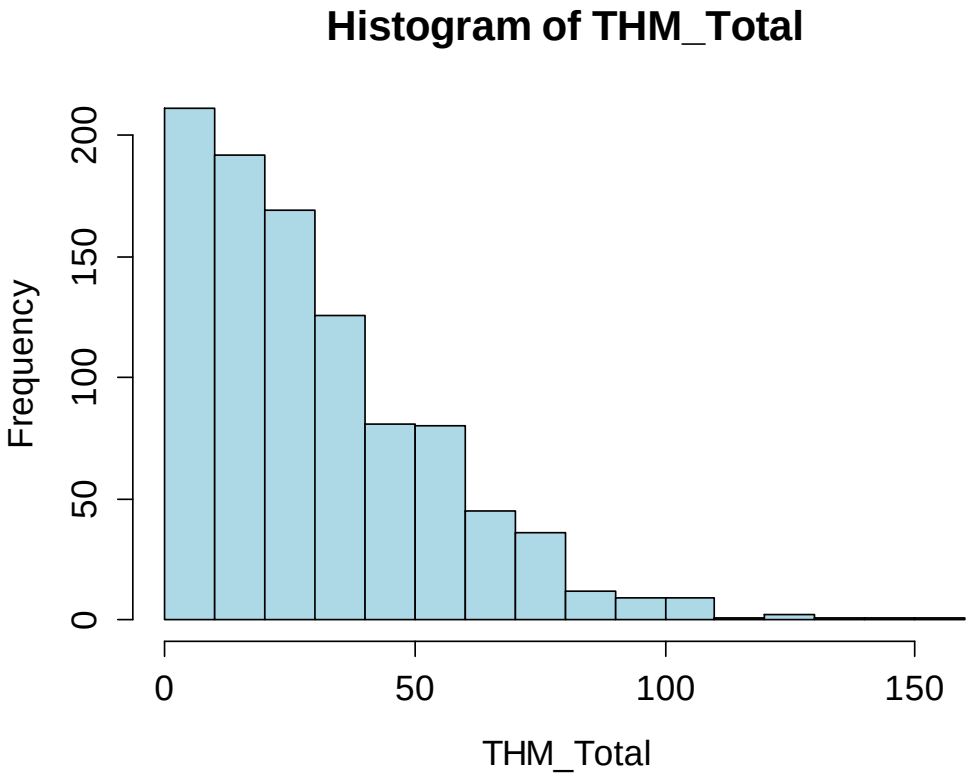

Figure 7.9 Histogram of THM total concentration (µg/L).

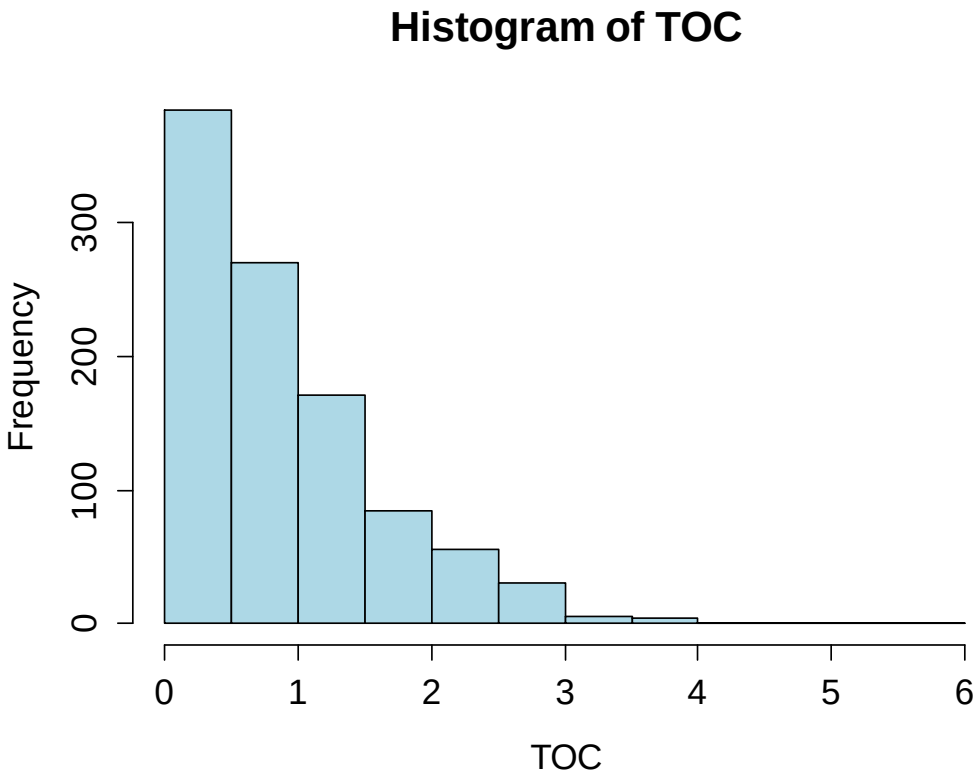

Figure 7.10 Histogram of TOC concentration (mg/L).

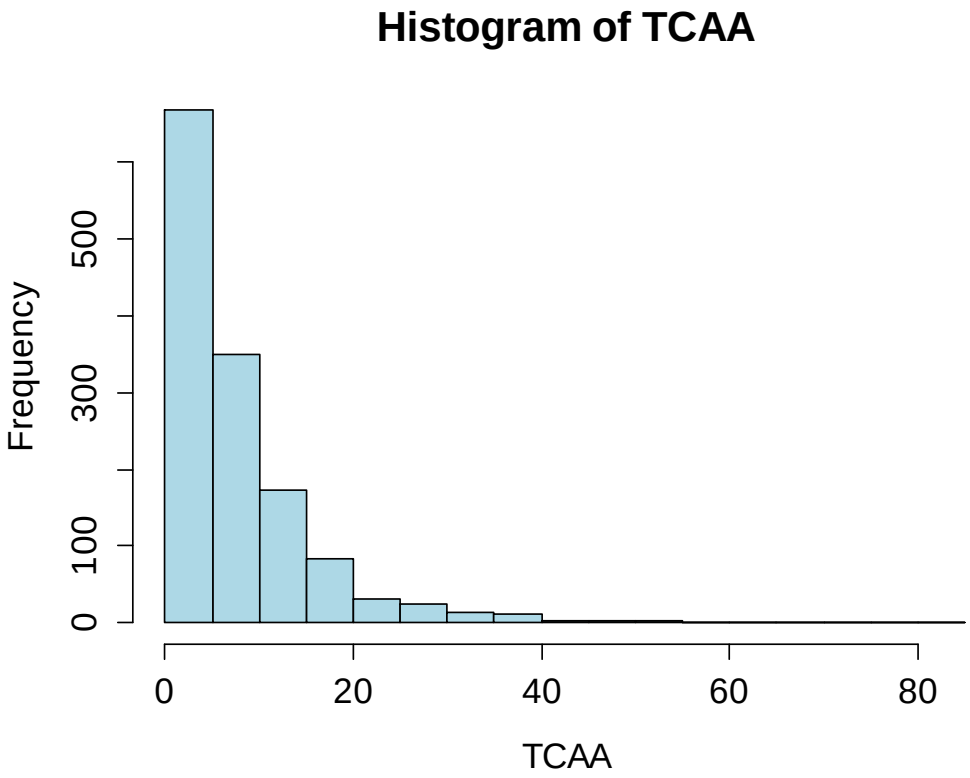

Figure 7.11 Histogram of TCAA concentration (µg/L).